WADD TECHNICAL REPORT 60-384

NITROGEN TETROXIDE CORROSION STUDIES

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WRIGHT AIR DEVELOPMENT DIVISION
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FOREWORD

This report was prepared by Nitrogen Division, Allied Chemical Corporation under USAF Contract No. AF 33(616)-6568 and Supplement Agreement No. 2(60-144). The contract was initiated under Project No. 7312, "Finishes and Materials Preservation", Task No. 73122, "Corrosion and Corrosion Prevention". The work was administered under the direction of Materials Central, Directorate of Advanced Systems Technology, Wright Air Development Division with Mr. Harold L. Stevens acting as project engineer.

This report covers work conducted from June 1959 to June 1960.

The work was performed in the Corrosion Laboratory of Nitrogen Division, Allied Chemical Corporation, Hopewell, Virginia. In addition to the authors, Mr. John L. Grinstead assisted in the experimental work and Mr. J. D. Ashton supervised construction of the apparatus. Messrs. W. D. Daley, T. J. McGonigle, and H. C. Wintser advised on special features of the project. Acknowledgement is made of advice and guidance rendered by Mr. R. C. Datin.

ABSTRACT

The purpose of this investigation was to determine quantitatively the corrosive effects of nitrogen tetroxide on mild steel, aluminum, stainless steels, and titanium. This was done under static conditions at six water concentrations up to 3.2 wt % and four temperatures up to 74°C. The corrosion rates under dynamic flow conditions were also investigated.

The corrosion of carbon steel (ASTM A-285 Grade C) and aluminum (5086) was less than 0.5 mil per year in nitrogen tetroxide containing up to 0.2 wt % water at 74°C, increasing to 50 mils per year at 3.2 wt % water and 74°C. Negligible corrosion was observed under severe conditions with stainless steel (304-L) and titanium (75A and 6Al-4V) whereas high strength steel (PH 15-7 Mo) showed losses of 0.5 to 1.0 mils per year. No stress corrosion cracking was observed in tests of carbon steel, high strength steel or aluminum in nitrogen tetroxide containing 0.1 and 1.6 wt % water at 49°C. Significant corrosion of stainless steel (304-L) occurred in the presence of Teflon.

Dynamic tests showed no significant corrosion of 304-L and PH 15-7 Mo stainless steels and average rates of 0.05 mils per year for aluminum and 0.33 mils per year for carbon steel after 205 hours exposure to commercial nitrogen tetroxide flowing at velocity of 10 ft per second at 30°C.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Richard R. Kennedy

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Chief, Metals and Ceramics Laboratory
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1. INTRODUCTION

1.01 Nitrogen tetroxide is a heavy brown liquid at ordinary temperatures containing about 30% nitrogen and 70% oxygen. In this form it consists principally of the tetroxide (N_2O_4) in equilibrium with a small amount of nitrogen dioxide (NO_2). This product is available in commercial quantities in very pure form containing less than 0.1% water. Nitrogen tetroxide is an economical and reliable storable liquid oxidizer for liquid-fueled rockets.

1.02 This project was initiated to quantitatively determine the corrosion of several metals and alloys in dry and wet liquid nitrogen tetroxide between the temperature limits of -9° to 74°C. The report summarizes the data from static tests on carbon steel (ASTM A-285, Grade C), stainless steel (304-L), aluminum (5086), welded aluminum (5086), titanium (75A and 6Al-4V), and high strength steel (PH 15-7 Mo). The durability of a number of elastomers was determined at 25°C. Data are also presented from several dynamic tests conducted by pumping commercial nitrogen tetroxide through a system containing carbon steel, stainless steel, high strength steel, aluminum, Teflon, and Kel-F specimens.

2. SUMMARY AND CONCLUSIONS

2.01 No significant corrosion of carbon steel (ASTM A-285, Grade C), stainless steel (304-L), aluminum (5086), precipitation hardened steel (PH 15-7 Mo), or titanium (75A and 6Al-4V) was found to occur during exposure of specimens to N_2O_4 containing up to 0.2 wt % water within the temperature range of -9° to 74°C.

2.02 Stainless steel (304-L) and titanium (75A and 6Al-4V) were virtually unattacked by N_2O_4 containing up to 3.2 wt % water at temperatures up to 74°C. Precipitation hardened steel (PH 15-7 Mo) was virtually unattacked except in N_2O_4 containing 1.6 and 3.2 wt % water at 74°C. Under these conditions a maximum corrosion of 2.1 mils per year was recorded.

2.03 Carbon steel and aluminum underwent corrosion at a faster rate during 3-day exposures than during 9- and 27-day exposures. Stainless steel was not subject to this initial attack.

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2.04 Corrosion rates on carbon steel and aluminum increase with temperature and water content of N_2O_4. In 27-day tests, the corrosion rates of carbon steel and aluminum were only 0.03 and 0.00 mils per year, respectively, at -9°C in N_2O_4 containing 0.2 wt % water. These rates increased to 27.5 and 48.6 mils per year for carbon steel and aluminum, respectively, at 74°C in N_2O_4 containing 3.2 wt % water.

2.05 Carbon steel, aluminum, and PH 15-7 Mo stainless steel stressed to the yield point showed no stress corrosion cracking as a result of immersion in liquid N_2O_4 containing 0.1 to 1.6 wt % water at 49°C for 41 days.

2.06 The corrosion of welded aluminum was not materially different from the unwelded aluminum. Microscopic examination of the welded aluminum specimen cross sections revealed that the corrosion was of the general type without visible pits or cracks.

2.07 The presence of Teflon increased the corrosion rate of stainless steel. For example, at 74°C in N_2O_4 containing 3.0 wt % water, the corrosion rate reached 4.58 mils per year in the presence of Teflon compared to a maximum rate of 0.17 mils per year recorded in the absence of Teflon. The corrosion of carbon steel also increased in the presence of Teflon. Aluminum corrosion was not materially affected in this regard.

2.08 Carbon steel, stainless steel, precipitation hardened stainless steel, and aluminum were tested at 30°C in commercial N_2O_4 flowing at 10 feet per second. The maximum average corrosion rate obtained was 0.33 mils per year on carbon steel during 205 hours exposure. The other metals were virtually unattacked.

2.09 Teflon and Kel-F were the most satisfactory non-metals tested. Asbestos-type gaskets gave good service.

2.10 Preliminary correlation of the data from the carbon steel and aluminum tests with the aid of the IBM-650 was of no particular advantage in interpreting test results.

3. MATERIALS

3.01 Nitrogen Tetroxide (N_2O_4). A 2000-pound cylinder of commercial N_2O_4 was obtained from Nitrogen Division, Allied Chemical Corporation. This material was analyzed with results shown in Table 1.

TABLE 1

N_2O_4 - ANALYSIS AND SPECIFICATION

	Analysis	Specification
N_2O_4 Assay, wt. %	99.9+	99.5
H_2O Equivalent, wt. %	0.004	0.1 max.
Cl as NOCl, wt. %	0.002	0.08 max.
Non-Volatiles (ash), wt. %	0.0008	0.01 max.

3.02 Metals. The supply of metals listed in Table 2 were obtained for these tests.

TABLE 2

TEST METALS

Metal	Designation	Supplier
Carbon Steel	ASTM A-285, Grade C	Morris, Wheeler and Co.
Aluminum	Alloy 5086-H34	Reynolds Metals Co.
Stainless Steel	Type 304-L	Steel Specialties, Inc.
Stainless Steel	15-7 Mo	Armco Steel Corporation
Titanium	75A and 6Al-4V	Titanium Corp. of America
Welded Aluminum	Alloy 5086	Richmond Engineering Co.

Mill tests, or certified analyses of the metals, are shown in Table 9, Appendix I.

3.03 Preparation of Test Specimens. Metal specimens for static tests were cut from strip or sheet stock. They were machined or wet ground to remove gross roughness, wet polished with 220A and 360A silicon carbide grit paper, stamped with an identifying number, scoured with "Old Dutch Cleanser", rinsed with water then acetone, and dried. 15-7 Mo specimens were precipitation hardened to Armco Condition RH-950 prior to final wet polishing. These specimens had a tensile strength of 236,000 psi. All specimens were stored in a dessicator until used.

3.04 Specimens for stress corrosion cracking tests were cut 7 inches long and 1/2 inch wide. Holes were drilled symmetrically 6 inches apart and all corners were broken. The specimens were bent almost to a U-shape. The stainless steel 15-7 Mo specimens were precipitation hardened to Armco

Condition RH-950 (actual measured tensile strength, 236,000 psi). The span across the ends of each specimen was measured, stud bolts were inserted and tightened until the gap had been reduced by 2 inches for PH 15-7 Mo, 7/8 in. for aluminum (5086), and 1/8 inch for carbon steel (ASTM A-285, Grade C). Finally, the stud bolts were removed and the gaps remeasured. If the gaps were less than originally measured, it was considered the yield point had been reached and the amount of tightening sufficient. Once the amount of tightening necessary to stress each specimen to its yield point had been determined, the stud bolts were retightened this amount and the convex surface carefully examined for cracks before use.

3.05 Welded aluminum specimens were prepared by butt-welding two strips of Alloy 5086 together, as described in Table 9, Appendix I. This material was sawed into 1 x 4 inch sections with the weld running across the 1-inch dimension. One side was machined until the weld and base metals presented one continuous flat surface.

4. EQUIPMENT

4.01 The initial static corrosion tests were conducted in 54 Teflon-lined aluminum containers obtained from the Wright Air Development Center. These containers were previously used by Bell Aircraft Corporation under Contract No. AF 33(616)-3056, Project No. 7312. Figure 1 is a dimensioned drawing of these containers. Figure 2 shows a closed and open container. Three specimens of the same metal were hung from the horizontal Teflon arms supported from a central Teflon rod.

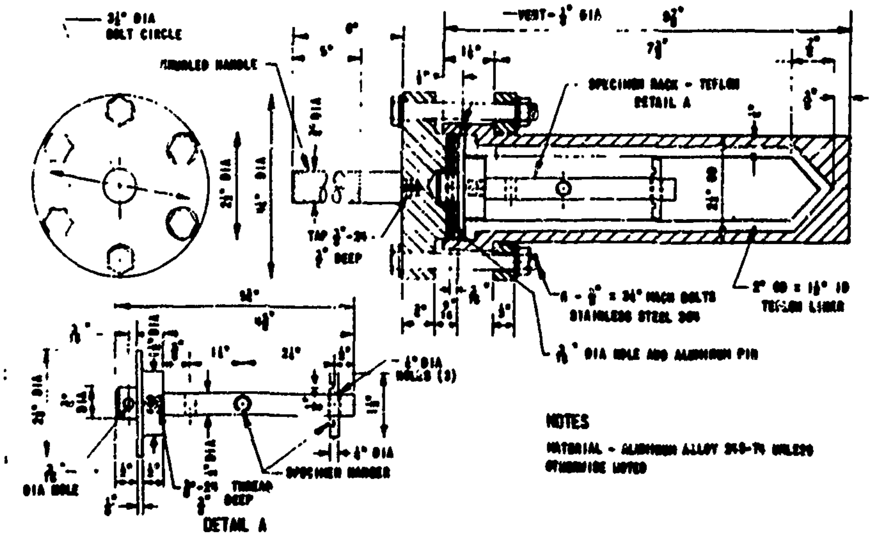
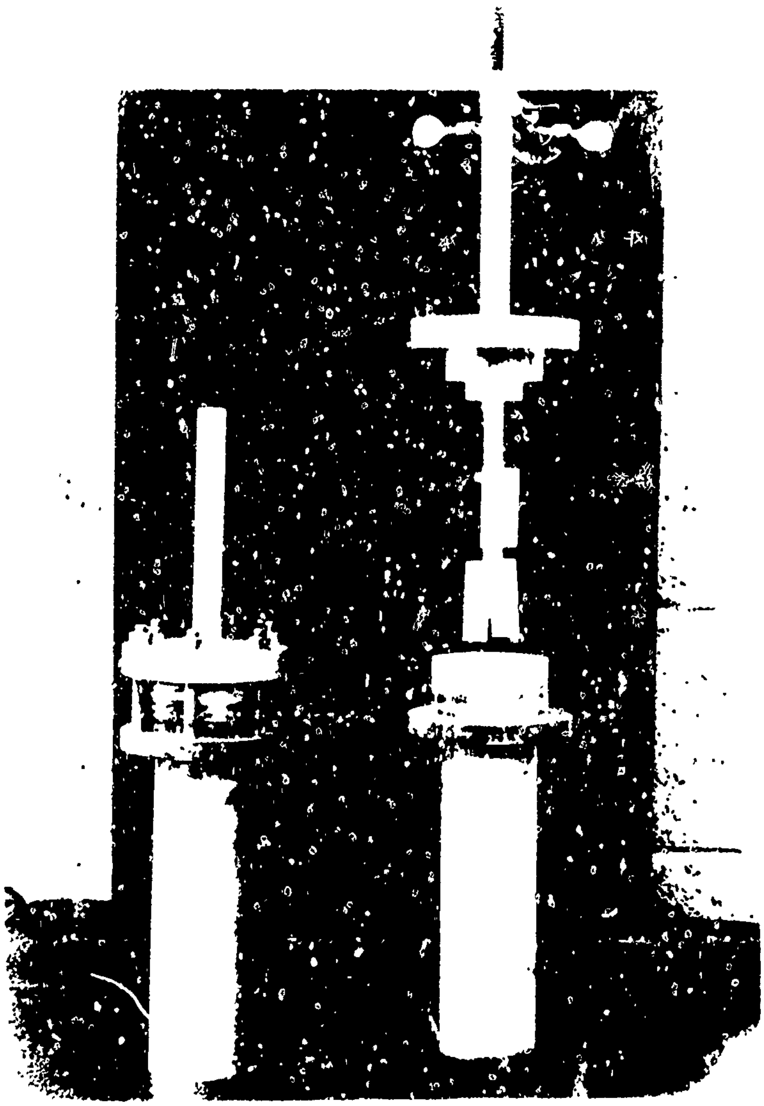


Fig. 1. Teflon-Lined Aluminum Container



Three metal specimens, each 1/2 x 1 inch were suspended from a glass tube for test purposes. The containers were placed in an automatically controlled temperature bath shown in Figures 5 and 6. A 5-gpm submerged pump provided circulation.

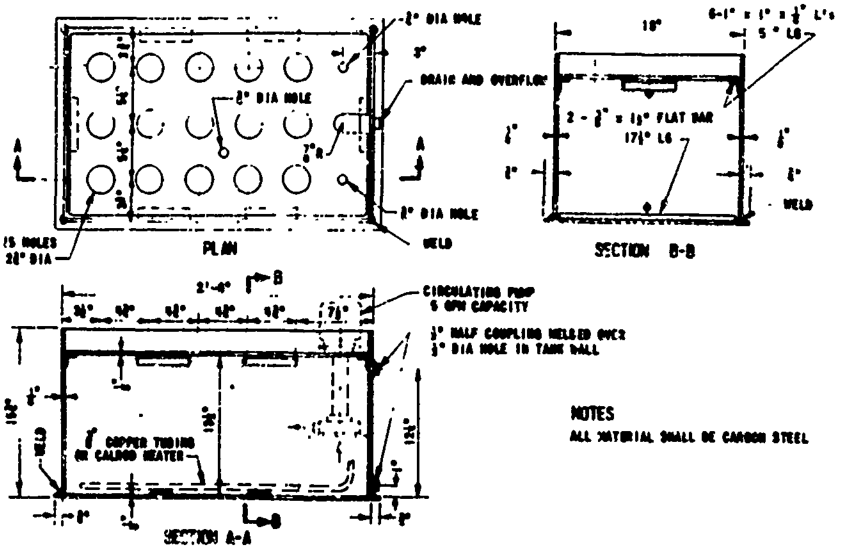


Fig. 5. Corrosion Testing Container Bath

4.03 Titanium specimens were tested in stainless steel (304-L) containers 12 inches deep and 4 inches in diameter fabricated as shown in Figure 7. 1 x 2 x 1/16 inch specimens were mounted on a carrier attached to the container head. Glass was used to insulate the specimens from each other and from the stainless steel. This arrangement is shown in Fig. 8. The bath assembly shown in Fig. 5 was fitted with a six-hole cover and remote controls for conducting the tests on titanium. This bath, enclosed in a concrete shelter, is pictured in Fig. 9.

4.04 Dynamic tests were conducted in a recirculating system containing a variety of metal and elastomer specimens. Fig. 10 shows the equipment that was originally assembled to run tests. Fig. 11 is a drawing of the equipment that was finally used. Several preliminary runs were made and pump packing failures made it necessary to replace the conventional centrifugal pump with a canned pump (Chempump Model CFH 1-1/2-3/4, Chempump Division, Fostoria Corporation).

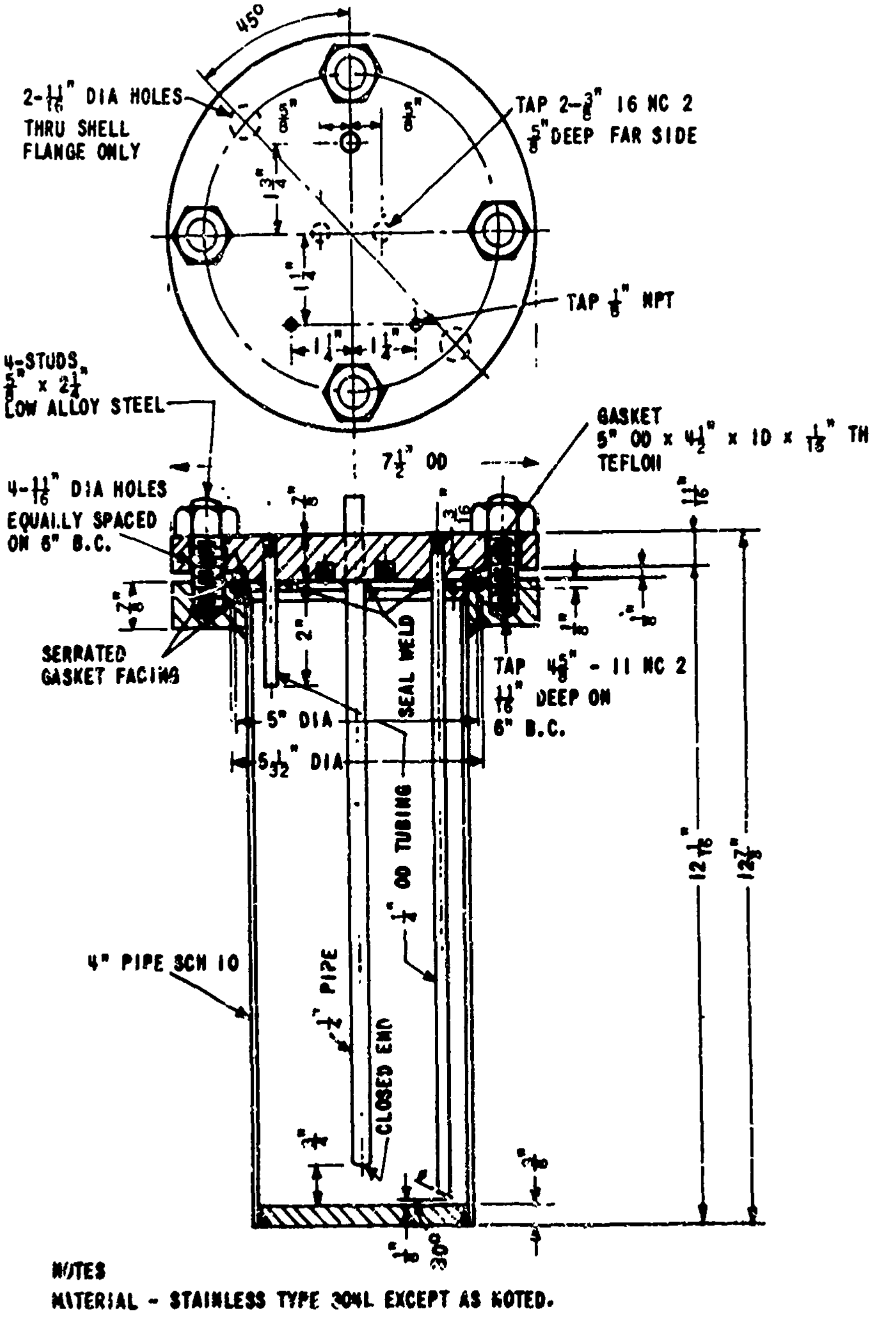


Fig. 7. Stainless Steel Container for Titanium Specimens

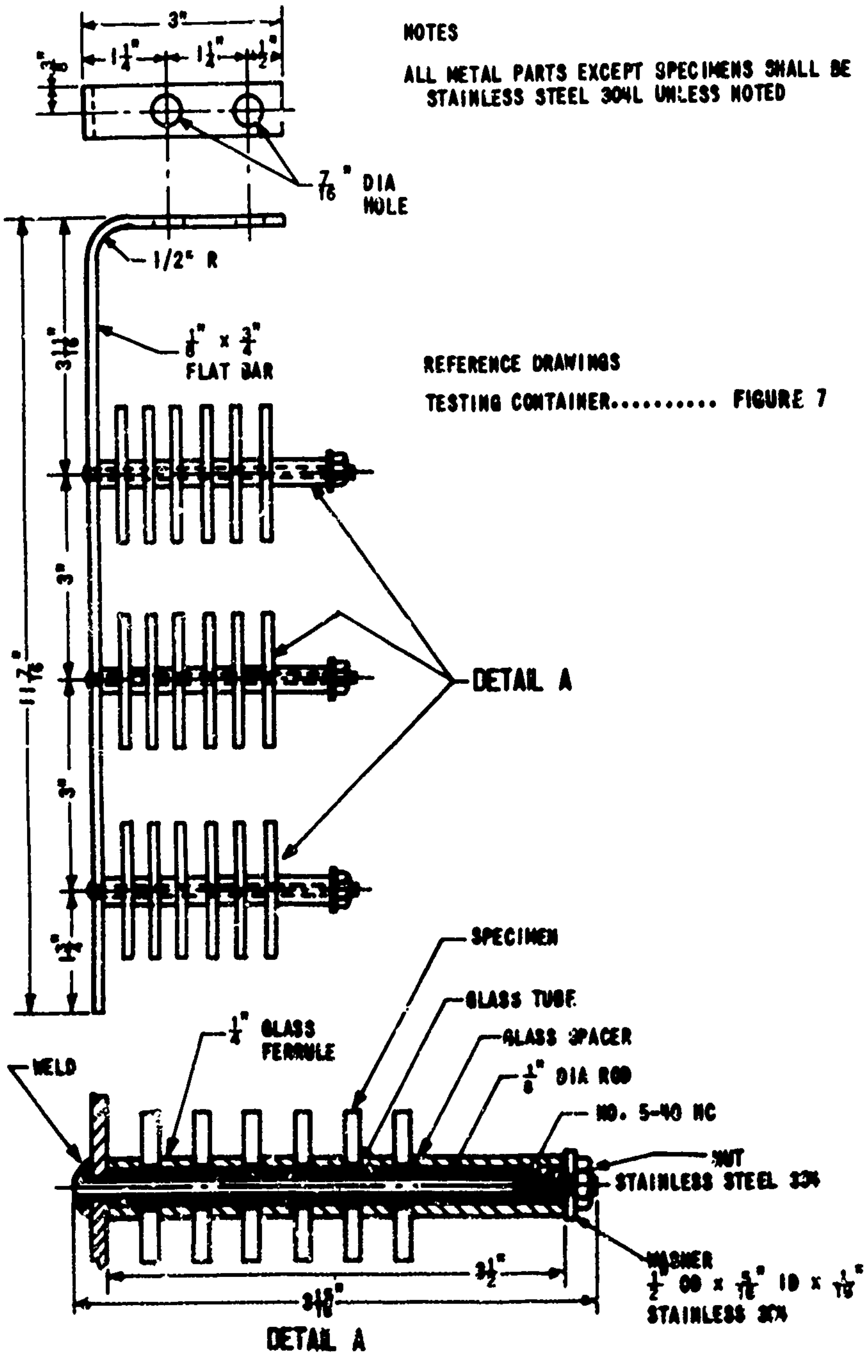
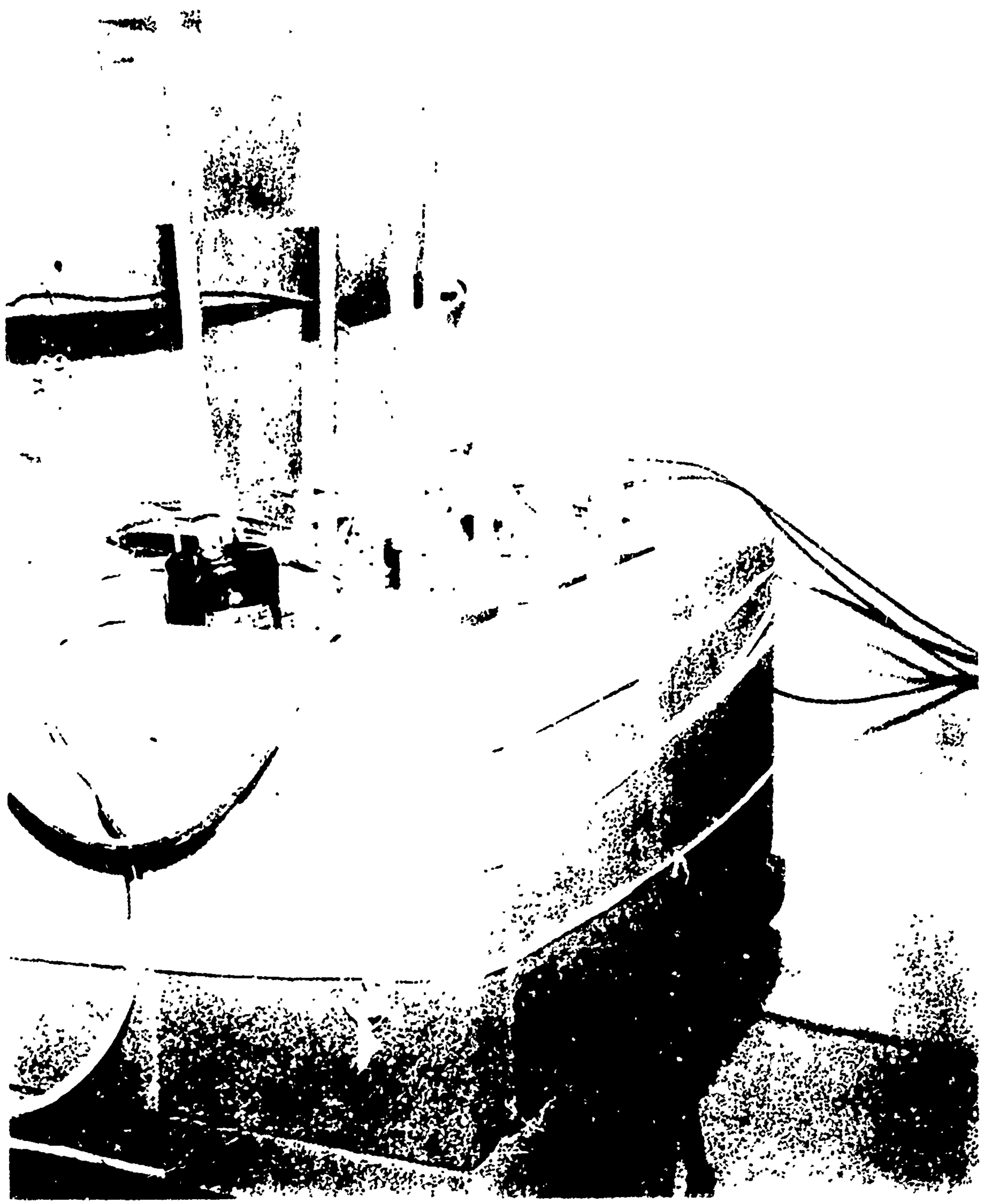


Fig. 8. Specimen Carrier for Stainless Steel Container



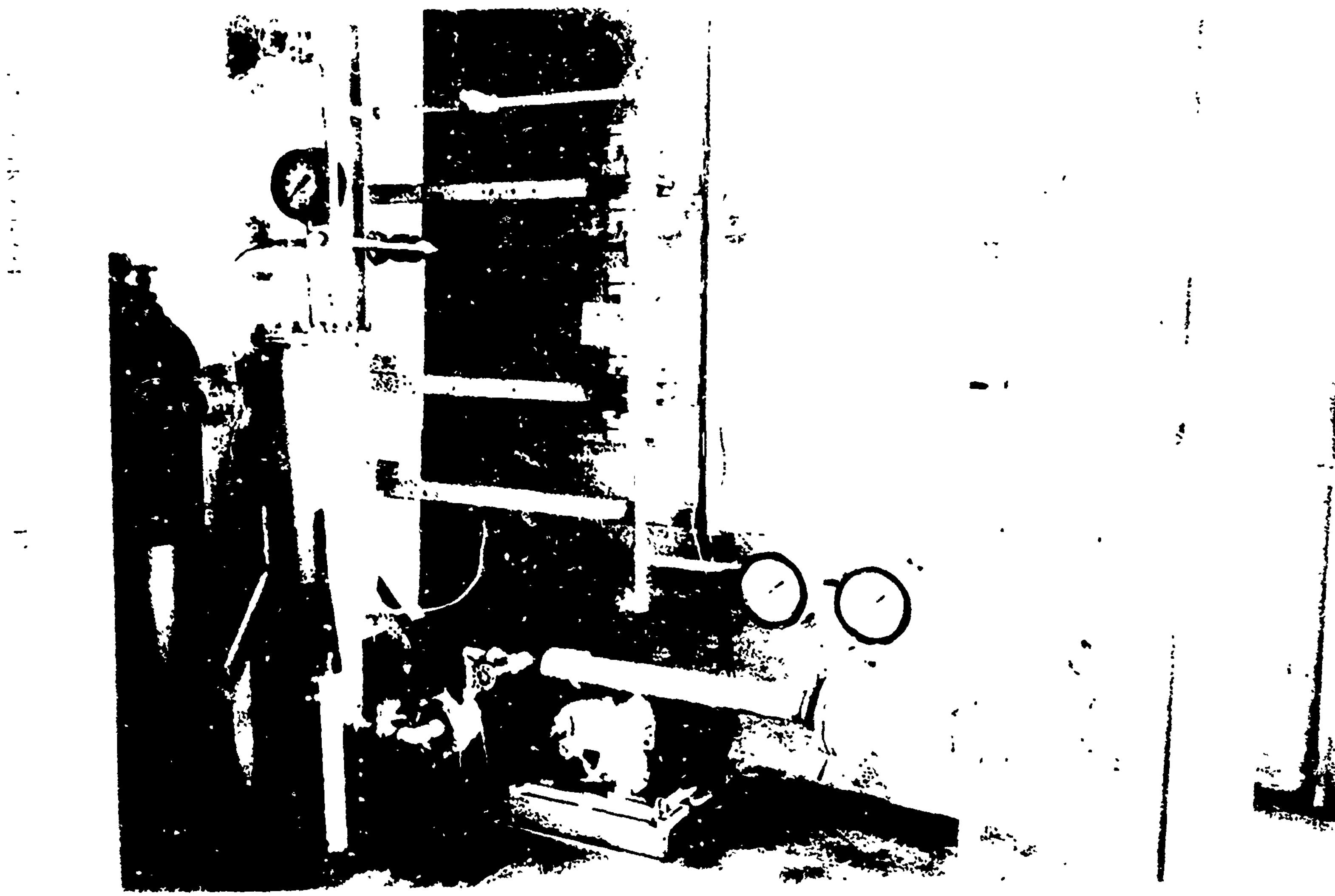


Fig. 10 N_2O_4 Recirculating Unit

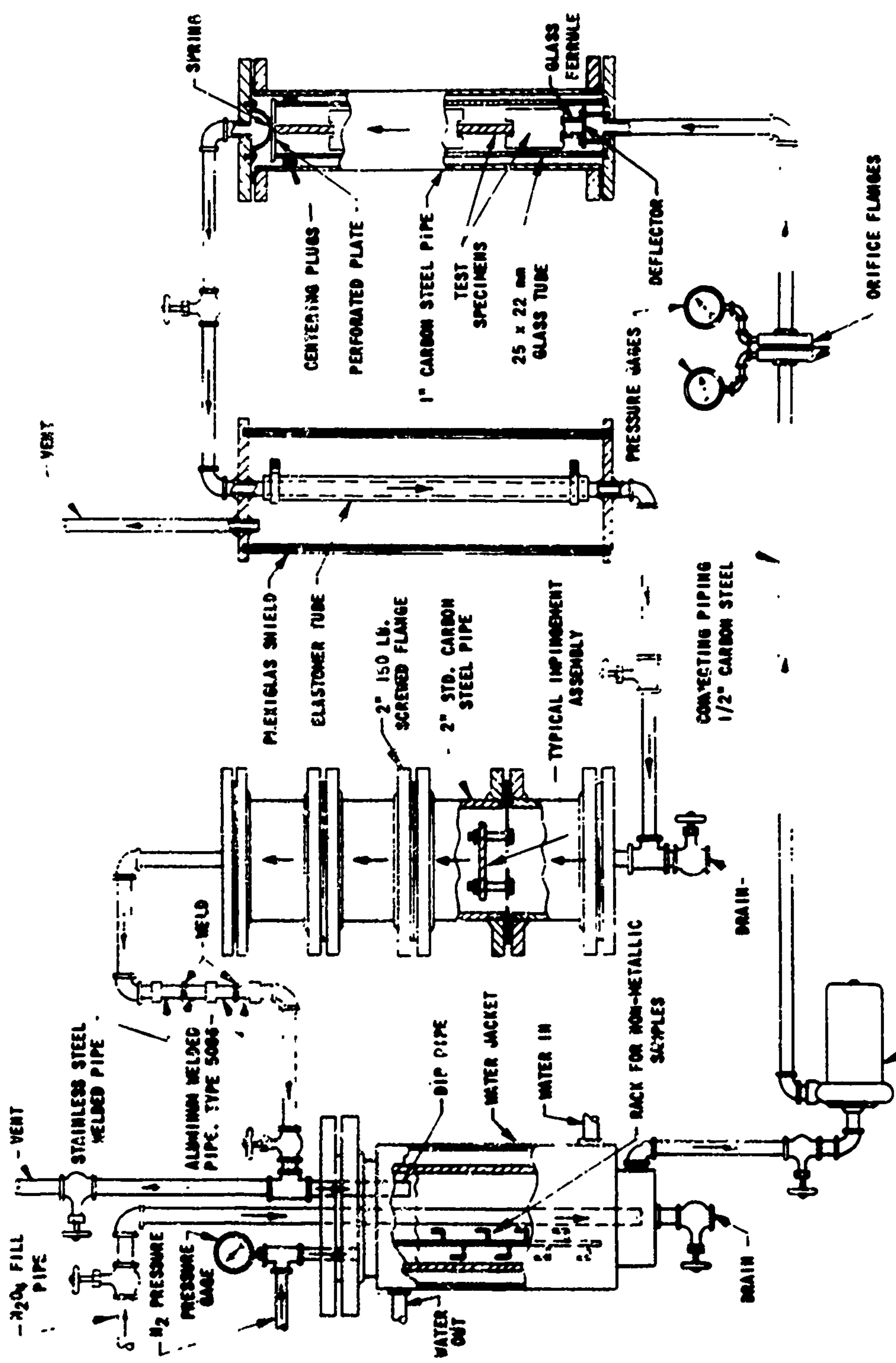


Fig. 11. Recirculating Unit - Assembly and Views

5. PROCEDURES

5.01 Static Tests in Teflon-Lined Containers. The containers were cleaned before using. Discolored Teflon liners were washed with 30% hydrochloric acid. All containers were soaked in water over night and then scrubbed with "Old Dutch Cleanser", water washed and dried with warm air. The Teflon top was pinned to the aluminum head so that the top with the center post, hanger arms, and specimens could be removed as a unit by means of a special jackscrew device.

5.02 Each container was cooled in ice water before charging. The desired amount of water was added and then 150 milliliters of liquid N_2O_4 was poured in. Triplicate specimens of the same metal were suspended on the Teflon hanger and the assembly inserted in the container. The head was tightened by applying 25 foot pounds of torque to each of the six hexagonal head nuts. The loaded containers were immediately placed in three thermostatically controlled baths. The temperatures were controlled as follows:

(1) 74°C $\pm$ 1.0°C throughout the 70 days of test

(2) 46°C $\pm$ 0.5°C throughout the 109 days of test

(3) -9°C $\pm$ 1.0°C throughout 56 days except one period of 23 hours heating to 20°C, then 26 hours to cool down to -9°C and 2 hours at -16°C.

5.03 After a period of 14 or 28 days, each container was removed from the bath, cooled to 0°C (except containers in the -9°C bath), opened and the specimens removed, scrubbed with a bristle brush and water, rinsed in acetone, dried and weighed. They were returned at once to the container, the head replaced and the test continued. At the conclusion of the test, the container was emptied and observations made of the amount of deposit, condition of the liner, and type of corrosion of the specimens.

5.04 Static Tests in Glass Tubes. This procedure was developed to avoid the increase in corrosion of carbon steel and stainless steel in the presence of Teflon at the more severe conditions. After removal of the Teflon liners, the containers were washed with 70% HNO_3, water, acetone, and then dried with warm air. Each container was cooled in an ice bath and 80 milliliters of liquid N_2O_4 was poured into the container to facilitate heat transfer and to maintain the proper vapor pressure on the outside of the glass tube. Simultaneously, the desired amount of water was added to a clean, dry 7-1/2 x 1-1/2 inch glass tube, the tree on which the metal specimens were supported was inserted in the tube, and 125 milliliters of liquid N_2O_4 was poured in the tube. The tube containing the specimens and environment was lowered into the container, and a glass cap placed on the tube. The container head gaskets were positioned and the head put in place and tightened by applying 25 foot pounds of torque to each of the hexagonal head nuts. The loaded containers were immediately placed in four baths. The temperature record showed the following variations:

(1) -9°C ± 2°C all tests.

(2) 21°C ± 1°C all tests except one period of 10 hours in the 9-day test of carbon steel and aluminum when temperature dropped to 9°C.

(3) 49°C ± 0.5°C all tests.

(4) 74°C ± 0.5°C all tests except one period of 6 hours for carbon steel and aluminum when temperature rose to 78°C.

5.05 Exposure times were 3, 9, and 27 days, each starting from zero time. This is a condition encountered in a single filling of a storage vessel. After the desired period of exposure, the containers were removed from the bath and chilled in ice water. The specimens were removed, scrubbed with a bristle brush in water, rinsed in acetone, then dried and weighed. The liquid N_2O_4 was observed for sludge formation, etc., but not reused. The specimens were reused after resurfacing, cleaning and weighing.

5.06 Stress Corrosion Tests. The stainless steel (304-L) containers (shown in Fig. 7) were washed with acetone, water, 70% HNO_3, water and acetone in the order named and then dried with warm air. Each container was cooled in an ice bath and the desired amount of water and 1000 milliliters of liquid N_2O_4 added. A Johns-Manville service gasket was used. The head (see Fig. 8) with the attached hanger assembly and specimens was positioned and tightened. The loaded containers were immediately placed in a bath with the temperature controlled at 49°C ± 0.5°C throughout two periods of exposure totaling 41 days. After the first exposure period of 14 days the specimens were cleaned and visually examined for cracks. The same specimens and liquid were used in both tests. At the conclusion of the second period of exposure (27 days) the specimens were cleaned, mounted and microscopically examined.

5.07 Titanium Studies. The stainless steel containers used in the stress corrosion tests were cleaned and dried. A blowout diaphragm was installed in each head. The head with the attached hanger assembly holding three 1 x 2 x 1/16 inch specimens of both 75A and 6Al-4V titanium was positioned and tightened. The containers were placed in a cold bath housed in a concrete shelter. Stainless steel lines were connected to the dip-pipe and to the vapor outlet of each container and extended outside of the shelter. A vacuum was drawn on each container and 1500 milliliters of N_2O_4 containing the desired amount of water was drawn into the container via the dip-pipe line. The valve through which the N_2O_4 was loaded was then closed. All six containers were charged in this manner and the bath brought to the desired temperature. During the test the constancy of bath temperature was controlled as follows:

(1) 21°C for 27 days ± 1°C

(2) 74°C for 9 days ± 1°C

(3) 74°C for 27 days ± 1°C

After the exposure period the dip-pipe lines were opened and the N_2O_4 discharged. Argon was blown in the dip-pipe lines and out the vapor lines until all traces of N_2O_4 disappeared. The containers were valved off, cooled, and carefully removed from the bath. They were opened, the specimens removed, scrubbed in water, dried, and weighed. All specimens were refinished (about 20 - 50 milligrams of metal removed) and reweighed for the next test. Specimens exposed for 27 days at 74°C were examined microscopically.

5.08 **Tests to determine the effects of Teflon were run by the same general procedure used for static tests on carbon steel and stainless steel except that some containers contained 322 square centimeters of Teflon (approximate area of Teflon liner in an aluminum container) and some did not contain Teflon. Metal specimens were scrubbed, rinsed, dried and weighed before and after each test to determine the amount of weight loss caused by the presence of Teflon.**

5.09 Welded aluminum was tested in N_2O_4 contained in capped glass tubes inserted in aluminum containers without the Teflon liners. The procedure was similar to that described in paragraph 5.04 except that only one specimen was placed in each tube. Glass trees were not used and the specimen was allowed to rest in the vertical position on the bottom of the tube. Tests were conducted with N_2O_4 containing 0.0, 0.4, and 3.2 wt. % water at -9°, 21°, 49°, and 74°C. Specimens were weighed before and after testing and those noticeably corroded were examined microscopically around the welded area cross section.

5.10 Dynamic Tests. The assembled piping was washed free of oil and other foreign matter by circulating carbon tetrachloride and then acetone. All traces of acetone were removed by purging with compressed air overnight. The materials to be tested were then placed in the clean recirculating system as shown in Fig. 11. Carbon steel, aluminum, stainless steel, and precipitation hardened steel specimens (2 x 3/4 x 1/16 or 1/8 inch) were mounted one above the other in a glass tube fitted inside a vertical metal pipe. Each specimen was separated from a dissimilar metal by a Kel-F ferrule to minimize galvanic effects. Kel-F and Teflon tubes, each 1/2 inch ID x 2 feet in length, were included in the piping. Disks (1-1/2 inches diameter) of stainless steel and carbon steel were tested separately with each disk mounted within the vena-contracta above a simple orifice to get impingement effects. Six plastic and three gasket specimens were suspended from a vertical rack in the reservoir. Also included in the piping were weighed ells of carbon steel and stainless steel (304), and welded nipples of carbon steel, stainless steel (304), and aluminum. The grades or types of the carbon steel and aluminum piping were not known.

5.11 The system was tested for leaks with nitrogen at 40 psi. Commercial N_2O_4 (see Table 1 for analysis) was charged until the reservoir filled to the overflow valve. The cooling water was turned on and the pump started to circulate the N_2O_4. At the conclusion of the first test (about 100 hours) the system pressure was vented and the N_2O_4 drained. The test materials in the reservoir and the non-welded metal specimens were removed. The metal specimens were brushed and washed with water, rinsed in acetone, dried, and weighed. The materials from the reservoir were examined for loss of strength and change in appearance. The metal specimens were returned to the system for the second test which was run by the same procedure with the solvent wash step eliminated. At the conclusion of the second test all specimens were examined.

6. DISCUSSION OF RESULTS

A. Static Tests in Teflon-Lined Aluminum Containers

6.01 The data from these static tests are presented in Tables 10 through 13, Appendix I. The weight loss for each metal specimen is given and the average of three values is converted to mils per year penetration. With few random exceptions, the corrosion was uniform, hence average penetration is a pertinent figure. In considering these results, it should be remembered that the presence of Teflon markedly increased the corrosion of stainless steel. Teflon also caused an increase in the corrosion rate of carbon steel in comparative tests but did not materially affect the corrosion of aluminum. The rates reported and discussed in this section apply to these special situations. Comparative tests with and without Teflon are discussed in paragraph 6.06.

6.02 Carbon Steel and Aluminum. Both metals exhibit a high initial loss for the first interval of exposure. On the subsequent exposure the rate drops to one-half to one-tenth the initial value and continues at a fairly steady rate throughout the tests. This pattern does not apply for the -9°C or no water tests. The relatively abrupt decrease in rate is believed due to a combination of corrodent depletion and passivation phenomena. The initial rates increase regularly with water content and temperature. Data from Tables 11 through 13, Appendix I, are rearranged and given in Table 3 for carbon steel and aluminum.

TABLE 3

INITIAL AND "STEADY STATE" RATES OF CORROSION FOR CARBON STEEL AND ALUMINUM IN THE PRESENCE OF TEFLON

	Carbon Steel ASTM A-285, Grade C							
	46°C				74°C			
Water added to N_2O_4, wt. %	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
Initial rate, mpy	3.6	5.6	-	16.3	8.3	13.3	25.6	40.5
Steady rate, mpy	1.1	2.0	-	1.5	0.5	1.0	4.0	3.5

	Aluminum 5086							
	46°C				74°C			
Water added to N_2O_4, wt. %	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
Initial rate, mpy	2.0	6.3	22.3	34.6	8.5	26.8	41.0	67.5
Steady rate, mpy	0.6	0.7	0.4	0.5	0.5	0.2	0.2	1.0

6.03 Stainless Steel. This material exhibits a lower initial rate and a more gradual decrease in rate with time due to the passivation characteristics normally expected rather than corrodent depletion. The incremental losses were plotted to obtain an approximate asymptotic rate that corresponds to the "steady state" used in Table 3. The data of Table 4 illustrate the effect of water and temperature on corrosion of stainless steel 304-L.

TABLE 4

INITIAL AND "STEADY STATE" RATES OF CORROSION FOR STAINLESS STEEL 304-L IN THE PRESENCE OF TEFLON

	46°C				74°C			
Water added to N_2O_4, wt. %	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
Initial rate, mpy	0.11	0.60	1.40	1.80	4.00	3.20	4.60	4.60
Steady rate, mpy	0.15	0.20	0.35	0.40	0.30	0.40	0.60	1.10

6.04 After the tests were discontinued the containers were emptied and examined with the following observations of interest:

(a) Corrosion of all specimens, except three (out of 175 tests), was classified as uniform attack.

(b) The Teflon linings were discolored in all runs but only slightly so where no water was added. The color could not be removed by ordinary means. Teflon was noticeably weaker and softer after exposure to N_2O_4 containing 2% water at 46°C and higher.

(c) Sludges were not formed at -9°C or at water concentrations of 0.5%, or less. The amount of sludge increased directly with water concentrations above 0.5% at 46° and 74°C.

(d) At 74°C, 3% water, stainless steel formed a greenish sludge, carbon steel formed a greenish brown sludge, and aluminum was covered with an adherent white corrosion product but did not form a sludge.

6.05 There was good agreement of weight losses of the three specimens from a single container. The loss for stainless steel at 0.5% water at 74°C was higher than obtained at 1% water; otherwise, the accumulative losses show a consistent upward trend with water added and temperature.

B. <u>Effect of Teflon</u>

6.06 The presence of Teflon in N_2O_4 containing water markedly increased the corrosion rate of carbon steel and stainless steel but did not significantly affect the corrosion of aluminum 5086. Table 14, Appendix I, summarizes the data that lead to this conclusion. As a result of these findings, tests in the Teflon-lined containers were discontinued.

6.07 The data in Table 14, Appendix I, are divided into three series, A through C. Series A is a group of tests conducted under mild conditions, 25°C, 1.0% water, that showed no significant difference in corrosion rate in presence or absence of Teflon. This led to the conclusion that Teflon was not a complicating factor; however, subsequent tests run at more severe conditions (3% H_2O, 74°C) set forth in this contract gave evidence that Teflon was being attacked and the corrosion rate of stainless steel was inordinately high. Accordingly, six comparative tests were conducted, shown as Series B in Table 14, at 3% water, 74°C, on stainless steel, carbon steel, and aluminum. Data from this series show that carbon steel and stainless steel were corroded at rates 10 to 20 times higher in the presence of Teflon than in its absence. The corrosion rates for aluminum were only slightly higher in the presence of Teflon. In the case of stainless steel Garlock's Teflon sheet packing showed the same effect as Teflon cut from a container liner. In order to determine how extensive the deleterious effect of Teflon might be, the tests shown in Series C were conducted on carbon steel at an intermediate condition of severity, 1% water, 46°C. Data from these comparative tests show that the rates are many times greater in the presence of Teflon than in its absence.

6.08 No attempt was made to determine the route or mechanism through which Teflon products react. One sample of N_2O_4, after exposure, was analyzed and found to contain less than one ppm fluorine. Further investigation was believed beyond the scope of this contract.

6.09 A brief test was conducted to determine the possibility of using stainless steel containers, constructed as shown in Figure 7, exposing three metals simultaneously to wet N_2O_4 in the absence of Teflon. The metals were galvanically insulated with glass, nevertheless, iron was abnormally attacked, a result that is not readily explained by electrochemical theory. The essential data are noted in Table 5 and compared to corresponding rates obtained for the same metals exposed separately.

TABLE 5

A COMPARISON OF CORROSION RATES OF CARBON STEEL, STAINLESS STEEL 304-L, AND ALUMINUM EXPOSED SEPARATELY AND SIMULTANEOUSLY IN N_2O_4, 3% WATER, FOR 7 DAYS AT 74°C

	Corrosion Rates, M.P.Y.	
Metal	Simultaneous	Separate
Carbon Steel	150	20
Aluminum	157	186
Stainless Steel	0.17	0.04

C. Static Tests in Capped Glass Tubes

6.10 The data from 338 static tests are presented in Tables 15 through 19, Appendix I. Carbon steel (ASTM A-285, Grade C), stainless steel(304-L), precipitation hardened stainless steel (PH 15-7 Mo, Armco Condition RH 950), and aluminum (5086) were exposed 3, 9, and 27 days at six water concentrations and four temperatures. Two grades of titanium (75A and 6Al-4V) were exposed 9 and 27 days at 74°C and six water concentrations, and 27 days at 21°C and six water concentrations. The weight loss for the three specimens of each test was averaged and the average converted to mils per year. Table 20, Appendix I, is a summary of the corrosion rates and reference is made to these data in the following paragraphs.

6.11 The effect of water concentration and temperature on corrosion rate may be appraised by considering two levels of water concentration at four temperatures. The data in Table 6 show the corrosion trends that may be expected in N_2O_4 containing 0.4% water, the maximum amount that should be found in any handling of N_2O_4, and 3.2% water, the maximum used in this investigation.

6.12 Carbon Steel ASTM A-285, Grade C. Temperature had only a slight effect on corrosion rate at 0.4% or less water. There was a large increase in rate due to temperature at 3.2% water. An eight-fold increase of water did not significantly increase the attack at -9°C but at 21°C and higher the corrosion rate increased many fold. With the exception of the 74°C tests, carbon steel did not exhibit the high initial attack that occurred in the presence of Teflon. No cases of pitting were observed.

TABLE 6

CONDENSED SUMMARY OF CORROSION RATES OF METALS IN N_2O_4 FOR 27 DAYS, CAPPED GLASS TUBES

Metal		Carbon Steel	Aluminum	304-L	PH 15-7 Mo	Titanium 75A	Titanium 6 Al-4V
Temp., °C	Water Added Wt. %	Penetration in Mils Per Year					
-9	0.40	0.04	0.07	0.01	0.01	-	-
21	0.40	0.03	0.15	0.02	0.00	0.01	0.00
49	0.40	0.99	0.35	0.02	0.00	-	-
74	0.40	1.12	1.69	0.02	0.00	0.00	0.00
-9	3.20	0.12	3.61	0.02	0.00	-	-
21	3.20	4.32	7.20	0.03	0.03	0.00	0.01
49	3.20	29.72	57.85	0.04	0.14	-	-
74	3.20	27.50	48.60	0.02	0.39	0.01	0.00

6.13 Stainless Steel 304-L. There was negligible attack on stainless steel except at 74°C where the maximum penetration rate of 0.17 mpy was recorded in a 27-day test containing no added water. In contrast, this metal showed in the presence of Teflon penetration rates as high as 4.58 mpy in a 14-day test at 74°C and 3% water.

6.14 Aluminum 5086. With few exceptions, this alloy of aluminum exhibited a greater susceptibility to attack than carbon steel at all water levels and temperatures. At concentrations less than 0.4% water, temperature does not exert a strong influence on the corrosion rate. Above 0.4% water and 21°C, both temperature and water concentration contribute directly to the corrosion rate. This was more pronounced in the 3-day test. Where corrosion occurred it was of the general type with a soft layer of white (green until washed free of N_2O_4) corrosion products forming over the entire aluminum surface.

6.15 Welded aluminum corrosion data are shown in Table 21, Appendix I. The corrosion penetration rate for the 27-day period in the absence of added water was less than 0.1 mpy, but rose to 32 mpy at 74°C, 3.2% water. The weld areas on the corroded specimens were outlined by a visible change in brightness at the junction of the weld and base metals; however, microscopic examination (50 to 400X) of specimen cross sections showed that corrosion was of the general type without visible surface pits or cracks.

6.16 PH 15-7 Mo Stainless Steel. This metal suffered very little attack (less than 0.2 mpy in N_2O_4 containing 0.4% water) under all conditions except at 74°C, 1.6 and 3.2% water, where the penetration rate was about 2.0 mils per year. Under these severe conditions, a very thin coating of black powder appeared on the metal surface. No pitting occurred.

6.17 A correlation of the corrosion data for carbon steel and aluminum was made by multiple regression procedures using an IBM-650 computer. Second order equations were derived expressing corrosion rates (penetration, mils per year) as a function of three variables; time, temperature, and wt % water added. These equations are reproduced below. The coefficients of multiple regression are fairly good for experimental corrosion data. The standard errors of estimate are somewhat high in comparison with the average thereby reducing the usefulness of these equations for predicting corrosion rates in the low attack areas.

Corrosion of carbon steel, mpy	Xc. s.
Duration of exposure, days	X_1
Wt. % water added	X_2
Temperature, °C	X_3

$$Xc.s. = 1.2749X_1^2 - 31.01X_1X_2 - 119.8X_1X_3 + 41.42X_2X_3 + .2703$$

Corrosion of aluminum, mpy	Xal.
Duration of exposure, days	X_1
Wt % water added	X_2
Temperature, °C	X_3

$$Xal. = 1.7017X_1^2 - 50.8057X_1X_2 - 140.883X_1X_3 + 287.786X_2^2 + 17.280X_3^2 - 1.94310$$

D. Static Tests of Titanium in Stainless Steel Containers

6.18 Titanium (75A and 6Al-4V) was not attacked at 21° or 74°C during exposures of 9 and 27 days in N_2O_4 containing 0 to 3.2% added water. Formation of pyrophoric compounds did not occur. Several exposed specimens were struck in the absence of N_2O_4 with a hammer with the only result that of denting the specimens.

E. Stress Corrosion Tests

6.19 Three metals, carbon steel, aluminum, and PH 15-7 Mo (condition RH950) stressed to the yield point were exposed at 49°C to N_2O_4 containing 0.1

and 1.6 wt % water. After 41 days no cracks were apparent by visual examination. Photomicrographs likewise did not reveal any signs of stress corrosion cracking.

F. Elastomers

6.20 Several plastics and types of rubber were exposed to liquid N_2O_4 at room temperature. Data are shown in Table 22, Appendix I. All but two, Kel-F and Teflon, failed to retain their original properties for more than a few hours. Koroseal was a borderline case, changing appearance and dimensions but becoming stiffer and much stronger after exposure and subsequent air drying. In this manner, all but Kel-F and Teflon were eliminated for possible use in transporting liquid N_2O_4 and these two were tested as described in paragraph 6.22.

G. Dynamic Tests

6.21 Two tests were run by circulating commercial N_2O_4 at 26° to 31°C, 12 to 15 gpm (about 10 ft/sec across metal specimens) in a closed system. Data are shown in Table 23, Appendix I. Average penetration rates for metals in both tests calculated on the basis of the circulation time are shown in Table 7.

TABLE 7

CORROSION RATES IN FLOWING COMMERCIAL N_2O_4 AT 26 - 31°C

Metal	Appearance	Average Corrosion Rate mpy
Carbon steel, ASTM A-285, Grade C	Slightly tarnished	0.33
Stainless steel, 304-L	Bright	0.01
Stainless steel, PH 15-7 Mo	Bright	0.00
Aluminum, 5086	Bright	0.05

Corrosion rates based on the total exposure time, including periods when the pump was not running, were lower. Welded nipples of carbon steel, stainless steel (304), and aluminum through which N_2O_4 returned to the reservoir were cut lengthwise. All welds and nipple interiors were in excellent condition. Stainless steel (304) and carbon steel ells removed from the piping were in excellent condition. The carbon steel (ASTM, A-285, Grade C) and stainless steel (304-L) impingement plates kept their original bright finish. The carbon steel plate showed a corrosion rate of 0.23 mpy. The stainless steel plate was not affected.

6.22 Teflon proved to be the most satisfactory of the plastics tested although it underwent a slight swelling and suffered a reduction in strength. Kel-F also swelled and lost strength as shown in Table 8.

TABLE 8

BURSTING STRENGTH AND BEND TESTS OF TEFLON AND KEL-F TUBES

	Teflon, 13/16 in. OD		Kel-F, 5/8 in. OD	
	Before	After	Before	After
Hours containing N_2O_4	0	624	0	381.5
Hours containing flowing N_2O_4	-	205	-	2.5
Bursting strength, psig	1000+	690	1000+	455
Bend in 21 inch horizontal length, inches				
Vertical load, grams				
0.0	7/16	2-5/8	1-1/4	3-1/2
136.5	1-1/2	3-7/8	1-7/8	11-1/4
536.5	4-1/2	7-1/2	4	-
1036.5	7-7/8	-	6-3/4	-

6.23 African Blue Asbestos and Teflon Impregnated Asbestos (Palmetto 1330) appeared to be unchanged by exposure in the reservoir. Teflon and Kel-F were only slightly discolored. Koroseal shrunk, polyvinyl chloride swelled, and Alathon crumbled. Johns-Manville Service Asbestos blistered and showed slight dimensional shrinkage; however, it gave excellent service as flange gaskets.

6.24 The canned pump (Chempump Model CFH 1-1/2-3/4) appeared to be unaffected by the 205 hours service. The wetted portion of the pump was constructed of stainless steel (316). The bearings, also wetted with N_2O_4, were made of Graphitar. This pump was run with an average suction pressure of about 6 psig and a discharge pressure of about 50 psig. Previously, a standard centrifugal pump (Worthington Model 3/4 CNG-4ZA) was used. It was equipped with the conventional lantern ring packing gland. Three grades of packing, African Blue Asbestos, Teflon cone or chevron rings, and Kel-F chevron rings were used, the latter lubricated with Kel-F 90 grease. In no case were more than 10 hours running time obtained without total failure of the packing.

APPENDIX I

TABLE 9

Certified Mill Test of Metals

TABLES 10 THROUGH 23

Corrosion Data of Materials Tested in N_2O_4

TABLE 9

CERTIFIED MILL TESTS OF MET

Material	Purchased From	Sheet No.	Heat No.	Chemical Composition
Carbon Steel ASTM A-285 Grade C Firebox Steel	Morris, Wheeler Co. Philadelphia, Pa. Order No. HNR24691	A-12	47281	C Mn P S Phoenix .16 .37 .016 .030
Type 304 ELC Stainless Steel	Steel Specialties, Inc. Order No. HNR24753	-	E86598	C Mn P S Si Cr Ni .024 1.38 .025 .012 .59 18.90 10.64
Aluminum Alloy 5086 - H34	Reynolds Metal Co. Louisville, Ky.	-	-	Si Fe Cu Mn Mg Cr Zn .40 .50 .10 0.2-0.7 3.5-4.5 .05-.25 .25 (from Reynolds Aluminum Sheet 2-4-6, dated March 16,
Titanium-Grade 75A	Titanium Metals Co. of America New York, N.Y. Order No. HNR25450	4-2	M-9082	C Fe N_2 H_2 .026 .28 .033 .004
Titanium - Grade 6AL-4V	Titanium Metals Co. of America New York, N.Y. Order No. HNR25450	12-1	M-8543	C Fe N_2 Al Va H_2 .028 .17 .011 6.0 4.1 .005
PH15-7 Mo Stainless Steel	Armco Steel Corp. Middletown, Ohio	-	56254	C Mn P S Si Cr Ni Mo .075 .60 .021 .006 .26 15.14 7.20 2.22
Aluminum Alloy 5086-Welded	Richmond Eng. Co. Richmond, Va.	-	-	Material supplied by Reynolds Metal Co. was sent to R butt ends were welded together with filler metal Type A at 100 amperes.

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TABLE 9

CERTIFIED MILL TESTS OF METALS

Chemical Composition	Physical Properties				
	Test No.	Yield Pt.	Tensile Strength	Elongation	105° Ber[illegible] Test Press Brake
C .16, Mn .37, P .016, S .030	-	36,700	56,100	31% - 8"	-
Mn 1.38, P .025, S .012, Si .59, Cr 18.90, Ni 10.64					
Fe .50, Cu .10, Mn 0.2-0.7, Mg 3.5-4.5, Cr .05-.25, Zn .25, Others Each .05, Others Total .15, Al Remainder Reynolds Aluminum Sheet 2-4-6, dated March 16, 1959)					
Fe .28, N_2 .033, H_2 .004	A2605 4L	82,500	102,200	21.0	1.9
	T	87,400	104,700	22.0	1.9
Fe .17, N_2 .011, Al 6.0, Va 4.1, H_2 .005	A-1364 12L	132,400	142,900	13.0	3.6
	T	142,100	148,500	12.5	3.9
Mn .60, P .021, S .006, Si .26, Cr 15.14, Ni 7.20, Mo 2.22	Condition RH950	219,000 Rockwell C 47	233,000	5-2"	-

al supplied by Reynolds Metal Co. was sent to Richmond Engineering Company for welding by the Heliarc process. Square ds were welded together with filler metal Type A.W.S. - A.S.T.M. E-5356 1/8" diameter using A.C. high frequency current amperes.

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TABLE 10

SUMMARY OF CORROSION RATES OF METALS TESTED
ALUMINUM CONTAINER

% Water Added			0.0	0.0	0.2	0.2	0.4	0.4	0.5	0.5	0.8	0.8	1.0
Temp. °C	Days Incre.	Days Accum.	Incre.	Accum.	Incre.	Accum.	Incre.	Accum.	Incre.	Accum.	Incre.	Accum.	Incr
			PENETRATION										
			CARBON STEEL ASTM										
-9	14	14	0.01	0.01	0.03	0.03	0.11	0.11			0.20	0.20	
-9	21	35	0.05	0.03	0.03	0.03	0.22	0.17			0.43	0.32	
-9	21	56	0.01	0.02	0.03	0.03	0.33	0.22			0.24	0.29	
46	28	28	0.02	0.02					3.56	3.56			5.6
46	28	56	0.17	0.10					1.56	2.56			2.1
46	25	81	0.21	0.13					1.25	2.12			0.9
46	28	109	0.22	0.16					1.07	1.86			2.0
74	14	14	0.06	0.06					8.28	8.28			13.
74	14	28	0.07	0.07					1.21	4.75			1.70
74	14	42	0.06	0.06					0.87	3.45			0.40
74	14	56	0.07	0.07					0.46	2.71			1.1
74	14	70	0.66	0.18					0.49	2.26			0.7
			STAINLESS STEEL										
-9	14	14	-	-	0.00	0.00	-	-			-	-	
-9	21	35	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00	
-9	21	56	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00	
46	28	28	0.00	0.00					0.11	0.11			0.60
46	28	56	0.00	0.00					0.41	0.26			0.5
46	25	81	0.00	0.00					0.30	0.27			0.4
46	28	109	0.00	0.00					0.23	0.26			0.3
74	14	14	0.01	0.01					3.99	3.99			3.1
74	14	28	0.00	0.01					1.98	2.99			1.5
74	14	42	0.00	0.00					1.37	2.45			1.1
74	14	56	0.00	0.00					1.03	2.09			0.8
74	14	70	0.00	0.00					0.79	1.83			0.6
			ALUMINUM 5086										
-9	14	14	0.05	0.05	0.04	0.04	0.10	0.10			2.88	2.88	
-9	21	35	0.00	0.03	0.00	0.02	0.09	0.09			0.63	1.76	
-9	21	56	0.00	0.02	0.04	0.03	0.08	0.09			0.51	1.34	
46	28	28	0.03	0.03					1.98	1.98			6.2
46	28	56	-	-					1.18	1.58			1.4
46	25	81	-	-					0.87	1.34			1.0
46	28	109	0.00	0.01					0.61	1.16			0.7
74	14	14	0.04	0.04					8.50	8.50			26.
74	14	28	0.00	0.02					0.45	4.48			0.00
74	14	42	0.00	0.01					0.72	3.22			0.10
74	14	56	0.02	0.02					1.39	2.77			0.3
74	14	70	0.03	0.02					0.16	2.24			0.2

IMPORTANT- Teflon was found to affect the corrosion rates of carbon steel and stainless steel. See the discus

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TABLE 10

ARY OF CORROSION RATES OF METALS TESTED IN STATIC N_2O_4 IN TEFLON-LINED ALUMINUM CONTAINERS

PENETRATION MILS PER YEAR															
0.4 Incre	0.4 Accum	0.5 Incre	0.5 Accum.	0.8 Incre.	0.8 Accum.	1.0 Incre.	1.0 Accum	1.6 Incre.	1.6 Accum.	2.0 Incre.	2.0 Accum.	3.0 Incre.	3.0 Accum.	3.2 Incre.	3.2 Accum.
CARBON STEEL ASTM A285 GRADE C															
0.11	0.11			0.20	0.20			0.53	0.53						
0.22	0.17			0.43	0.32			0.60	0.57						
0.33	0.22			0.24	0.29			0.83	0.65						
		3.56	3.56			5.62	5.62			-	-	16.27	16.27		
		1.56	2.56			2.12	3.87			-	-	4.89	10.58		
		1.25	2.12			0.93	2.89			-	-	1.98	7.71		
		1.07	1.86			2.06	2.68			4.56	4.56	1.26	6.10		
		8.28	8.28			13.34	13.34			25.63	25.63	40.46	40.46		
		1.21	4.75			1.70	7.52			2.56	14.10	3.41	21.94		
		0.87	3.45			0.40	5.15			0.95	9.71	0.94	14.94		
		0.46	2.71			1.13	4.14			4.00	8.29	0.63	11.36		
		0.49	2.26			0.71	3.46			3.83	7.39	3.47	9.78		
STAINLESS STEEL 304 L															
-	-			-	-			0.02	0.02						
0.00	0.00			0.00	0.00			0.00	0.01						
0.00	0.00			0.00	0.00			0.00	0.01						
		0.11	0.11			0.60	0.60			1.36	1.36	1.79	1.79		
		0.41	0.26			0.58	0.59			0.97	1.17	1.11	1.45		
		0.30	0.27			0.43	0.54			0.73	1.02	0.82	1.35		
		0.23	0.26			0.34	0.49			0.55	0.90	0.63	1.17		
		3.99	3.99			3.19	3.19			4.58	4.58	4.58	4.58		
		1.98	2.99			1.68	2.44			2.74	3.66	3.12	3.85		
		1.37	2.45			1.13	2.00			1.88	3.07	2.28	3.33		
		1.03	2.09			0.82	1.71			1.42	2.66	1.81	2.95		
		0.79	1.83			0.65	1.49			1.05	2.33	1.49	2.66		
ALUMINUM 5086															
0.10	0.10			2.88	2.88			4.04	4.04						
0.09	0.09			0.63	1.76			1.79	2.82						
0.08	0.09			0.51	1.34			0.85	2.16						
		1.98	1.98			6.28	6.28			22.31	22.31	34.61	34.61		
		1.18	1.58			1.41	3.85			0.99	11.65	0.94	17.78		
		0.87	1.34			1.08	2.92			0.52	7.94	0.53	12.03		
		0.61	1.16			0.72	2.37			0.39	6.05	0.47	9.14		
		8.50	8.50			26.79	26.79			41.45	41.45	67.54	67.54		
		0.45	4.48			0.00	13.40			0.23	20.84	0.61	34.08		
		0.72	3.22			0.10	8.96			0.57	14.08	0.92	23.02		
		1.39	2.77			0.31	6.80			0.10	10.59	0.16	17.31		
		0.16	2.24			0.20	5.48			0.13	8.50	0.96	14.04		

s of carbon steel and stainless steel. See the discussion under Effects of Teflon.

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TABLE 11

CORROSION RATES OF CARBON STEEL (ASTM A285 GRADE C) IN STATIC N_2O_4 IN TEFLON-LINED ALUMINUM CONTAI

PENETRATION IN MILS PER YEAR

Temperature		-9°C(16°F)					46°C(115°F)					
Water Added, Wt %		0.0	0.2	0.4	0.8	1.6	0.0	0.5	1.0	2.0	3.0	0.0
Days in Period		14	14	14	14	14	28	28	28		28	14
mg Loss	A	0.1	1.3	2.0	5.3	12.5	1.1	196.0	279.8		867.9	1.9
	B	1.0	0.4	2.8	4.4	12.1	1.0	170.7	275.6		794.3	1.6
	C	0.1	0.5	3.1	5.2	14.8	0.6	176.4	282.3		788.4	1.2
	Avg.	0.4	0.7	2.6	5.0	13.1	0.9	181.0	279.2		816.9	1.7
Penetration(1)	Avg.	0.01	0.03	0.11	0.20	0.53	0.02	3.56	5.62		16.27	0.06
Penetration(2)	Avg.	0.01	0.03	0.11	0.20	0.53	0.02	3.56	5.62		16.27	0.06
Days in Period		21	21	21	21	21	28	28	28		28	14
Days Total		35	35	35	35	35	56	56	56		56	28
mg Loss	A	1.0	1.3	8.0	16.8	23.6	8.7	79.5	108.4		253.1	-
	B	1.5	1.6	9.1	17.6	27.4	9.0	76.0	102.1		240.9	2.5
	C	2.4	0.9	6.7	12.6	18.4	8.4	83.1	106.4		242.3	1.4
	Avg.	1.6	1.3	7.7	15.7	23.1	8.7	79.5	105.6		245.4	2.0
Penetration(1)	Avg.	0.05	0.03	0.22	0.43	0.60	0.17	1.56	2.12		4.89	0.07
Penetration(2)	Avg.	0.03	0.03	0.17	0.32	0.57	0.10	2.56	3.87		10.58	0.07
Days in Period		21	21	21	21	21	25	25	25		25	14
Days Total		56	56	56	56	56	81	81	81		81	42
mg Loss	A	0.5	1.3	12.0	9.4	26.4	10.2	57.7	42.1		92.2	3.0
	B	0.7	1.1	14.6	9.5	31.8	9.4	54.2	39.9		88.6	2.4
	C	0.0	1.0	9.3	7.4	33.3	8.4	58.1	42.1		85.9	0.7
	Avg.	0.4	1.1	12.0	8.8	30.5	9.3	56.7	41.4		88.9	2.0
Penetration(1)	Avg.	0.00	0.03	0.33	0.24	0.83	0.21	1.25	0.93		1.98	0.06
Penetration(2)	Avg.	0.02	0.03	0.27	0.29	0.65	0.13	2.12	2.89		7.71	0.06
Days in Period							28	28	28	109	28	14
Days Total							109	109	109	109	109	56
mg Loss	A						11.7	53.7	104.3	863.7	67.8	2.1
	B						11.4	54.1	99.0	886.6	61.8	2.0
	C						9.9	55.0	104.0	926.5	60.7	1.8
	Avg.						11.0	54.3	102.4	892.3	63.4	2.0
Penetration(1)	Avg.						0.22	1.07	2.06	4.56	1.26	0.07
Penetration(2)	Avg.						0.16	1.86	2.68	4.56	6.10	0.07
Days in Period												14
Days Total												70
mg Loss	A											30.4
	B											20.0
	C											3.9
	Avg.											18.1
Penetration(1)	Avg.											0.66
Penetration(2)	Avg.											0.18

IMPORTANT- Teflon was found to affect the corrosion rate of carbon steel. See the discussion under Effec

(1) Penetration MPY Increment.
(2) Penetration MPY Accumulative.

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TABLE 11

CORROSION RATES OF CARBON STEEL
A285 GRADE C) IN STATIC N_2O_4 IN TEFLON-LINED ALUMINUM CONTAINERS

PENETRATION IN MILS PER YEAR

-9°C(16°F)				46°C(115°F)					74°C(165°F)				
.2	0.4	0.8	1.6	0.0	0.5	1.0	2.0	3.0	0.0	0.5	1.0	2.0	3.0
[illegible]	14	14	14	28	28	28		28	14	14	14	14	14
3	2.0	5.3	12.5	1.1	196.0	279.8		867.9	1.9	222.6	367.1	696.2	1096.6
4	2.8	4.4	12.1	1.0	170.7	275.6		794.3	1.6	227.5	366.4	703.8	1118.3
5	3.1	5.2	14.8	0.6	176.4	282.3		788.4	1.2	228.3	367.3	692.5	1095.0
7	2.6	5.0	13.1	0.9	181.0	279.2		816.9	1.7	226.1	366.9	697.5	1103.3
03	0.11	0.20	0.53	0.02	3.56	5.62		16.27	0.06	8.28	13.34	25.63	40.46
03	0.11	0.20	0.53	0.02	3.56	5.62		16.27	0.06	8.28	13.34	25.63	40.46
1	21	21	21	28	28	28		28	14	14	14	14	14
5	35	35	35	56	56	56		56	28	28	28	28	28
.3	8.0	16.8	23.6	8.7	79.5	108.4		253.1	-	33.1	47.8	73.6	93.3
.6	9.1	17.6	27.4	9.0	76.0	102.1		240.9	2.5	34.3	45.5	67.7	89.7
.9	6.7	12.6	18.4	8.4	83.1	106.4		242.3	1.4	31.8	46.6	68.1	95.9
.3	7.7	15.7	23.1	8.7	79.5	105.6		245.4	2.0	33.1	46.6	69.8	93.0
.03	0.22	0.43	0.60	0.17	1.56	2.12		4.89	0.07	1.21	1.70	2.56	3.41
.03	0.17	0.32	0.57	0.10	2.56	3.87		10.58	0.07	4.75	7.52	14.10	21.94
1	21	21	21	25	25	25		25	14	14	14	14	14
6	56	56	56	81	81	81		81	42	42	42	42	42
.3	12.0	9.4	26.4	10.2	57.7	42.1		92.2	3.0	24.4	11.0	24.8	24.6
.1	14.6	9.3	31.8	9.4	54.2	39.9		88.6	2.4	25.0	10.6	25.5	26.1
.0	9.3	7.4	33.3	8.4	58.1	42.1		85.9	9.7	22.5	10.9	26.9	26.3
.1	12.0	8.8	30.5	9.3	56.7	41.4		88.9	2.0	23.9	10.8	25.7	25.7
.03	0.33	0.24	0.83	0.21	1.25	0.93		1.98	0.06	0.87	0.40	0.95	0.94
.03	0.22	0.29	0.65	0.13	2.12	2.89		7.71	0.06	3.45	5.15	9.71	14.94
				28	28	28	109	28	14	14	14	14	14
				109	109	109	109	109	56	56	56	56	56
				11.7	53.7	104.3	663.7	67.8	2.1	12.3	30.9	107.9	17.3
				11.4	54.1	99.0	886.6	61.8	2.0	13.7	31.3	107.9	17.0
				9.9	55.0	104.0	926.5	60.7	1.8	14.4	31.1	110.8	17.5
				11.0	54.3	102.4	892.3	63.4	2.0	13.5	31.1	108.9	17.3
				0.22	1.07	2.06	4.56	1.26	0.07	0.46	1.15	4.00	0.63
				0.16	1.86	2.68	4.56	6.10	0.07	2.71	4.14	8.29	11.36
									14	14	14	14	14
									70	70	70	70	70
									30.4	13.9	19.6	101.8	88.0
									20.0	13.6	19.2	102.1	103.1
									3.9	12.6	19.8	108.5	92.9
									18.1	13.4	19.5	104.1	94.7
									0.66	0.49	0.71	3.83	3.47
									0.18	2.26	3.46	7.39	9.78

to affect the corrosion rate of carbon steel. See the discussion under Effects of Teflon.

ement.
umulative.

TABLE 12

CORROSION RATES OF TYPE 304-L STAINLESS STEEL IN STATIC N_2O_4 IN TEFLON-LINE

PENETRATION IN MILS PER YEAR

Temperature		-9°C(15°F)					46°C(115°F)				
Water Added, Wt %		0.0	0.2	0.4	0.8	1.6	0.0	0.5	1.0	2.0	3.0
Days in Period			14			14	28	28	28	28	28
mg Loss	A		0.0			0.5	0.0	4.9	26.2	60.1	80.8
	B		0.0			0.3	0.0	5.1	28.0	60.5	83.3
	C		0.0			0.4	0.0	5.5	29.0	61.9	82.5
	Avg.		0.0			0.4	0.0	4.9	27.7	60.8	82.2
Penetration(1)	Avg.		0.00			0.02	0.00	0.11	0.60	1.36	1.79
Penetration(2)	Avg.		0.00			0.02	0.00	0.11	0.60	1.36	1.79
Days in Period		35	21	35	35	21	28	28	28	28	28
Days Total		35	35	35	35	35	56	56	56	56	56
mg Loss	A	0.0	0.0	0.0	0.0	0.0	0.2	18.4	26.4	42.4	49.6
	B	0.0	0.0	0.0	0.0	0.0	0.1	18.7	27.5	44.4	51.4
	C	0.0	0.0	0.0	0.0	0.0	0.1	18.7	26.4	43.6	51.8
	Avg.	0.0	0.0	0.0	0.0	0.0	0.1	18.6	26.8	43.5	50.9
Penetration(1)	Avg.	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.58	0.97	1.12
Penetration(2)	Avg.	0.00	0.00	0.00	0.00	0.01	0.00	0.26	0.59	1.17	1.45
Days in Period		21	21	21	21	21	25	25	25	25	25
Days Total		56	56	56	56	56	81	81	81	81	81
mg Loss	A	0.0	0.0	0.0	0.3	0.0	0.0	12.2	17.5	29.0	33.1
	B	0.1	0.0	0.0	0.3	0.0	0.0	12.6	18.1	29.5	33.6
	C	0.0	0.0	0.0	0.0	0.0	0.1	12.4	17.4	29.2	34.1
	Avg.	0.0	0.0	0.0	0.2	0.0	0.0	12.4	17.7	29.2	33.6
Penetration(1)	Avg.	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.43	0.73	0.82
Penetration(2)	Avg.	0.00	0.00	0.00	0.00	0.01	0.00	0.27	0.54	1.02	1.24
Days in Period							28	28	28	28	28
Days Total							109	109	109	109	109
mg Loss	A						0.0	10.7	15.4	24.3	28.0
	B						0.0	10.9	15.7	25.2	29.2
	C						0.0	10.7	15.5	24.2	29.1
	Avg.						0.0	10.8	15.5	24.6	28.6
Penetration(1)	Avg.						0.00	0.23	0.34	0.55	0.63
Penetration(2)	Avg.						0.00	0.26	0.49	0.90	1.09
Days in Period											
Dayc Total											
mg Loss	A										
	B										
	C										
	Avg.										
Penetration(1)	Avg.										
Penetration(2)	Avg.										

IMPORTANT- These rates are known to be high because of the presence of Teflon.

(1) Penetration MPY Increment.
(2) Penetration MPY Accumulative.

TABLE 12

RATES OF TYPE 304-L STAINLESS STEEL IN STATIC N_2O_4 IN TEFLON-LINED ALUMINUM CONTAINERS

PENETRATION IN MILS PER YEAR

	-9°C(15°F)					46°C(115°F)					74°C(165°F)				
	0.0	0.2	0.4	0.8	1.6	0.0	0.5	1.0	2.0	3.0	0.0	0.5	1.0	2.0	3.0
		14			14	28	28	28	28	28	14	14	14	14	14
		0.0			0.5	0.0	4.0	26.2	60.1	80.8	0.3	98.3	75.1	118.0	115.3
		0.0			0.3	0.0	5.1	28.0	60.5	83.3	0.0	111.2	83.0	118.1	118.7
		0.0			0.4	0.0	5.5	29.0	61.9	82.5	0.2	97.1	88.2	112.8	115.9
vg.		0.0			0.4	0.0	4.9	27.7	60.8	82.2	0.2	102.2	82.1	116.3	116.6
vg.		0.00			0.02	0.00	0.11	0.60	1.36	1.79	0.01	3.99	3.19	4.58	4.58
vg.		0.00			0.02	0.00	0.11	0.60	1.56	1.79	0.0	3.99	3.19	4.58	4.58
	35	21	35	35	21	28	28	28	28	28	14	14	14	14	14
	35	35	35	35	35	56	56	56	56	56	28	28	28	28	28
	0.0	0.0	0.0	0.0	0.0	0.2	18.4	26.4	42.4	49.6	0.0	50.4	42.2	72.3	79.5
	0.0	0.0	0.0	0.0	0.0	0.1	18.7	27.5	44.4	51.4	0.0	52.1	43.1	69.3	79.0
	0.0	0.0	0.0	0.0	0.0	0.1	18.7	26.4	43.6	51.8	0.0	50.0	45.0	67.2	79.5
vg.	0.0	0.0	0.0	0.0	0.0	0.1	18.6	26.8	43.5	50.9	0.0	50.8	43.4	69.6	79.3
vg.	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.58	0.97	1.11	0.00	1.98	1.68	2.74	3.12
vg.	0.00	0.00	0.00	0.00	0.01	0.00	0.26	0.59	1.17	1.45	0.01	2.99	2.44	3.66	3.25
	21	21	21	21	21	25	25	25	25	25	14	14	14	14	14
	56	56	56	56	56	81	81	81	31	81	42	42	42	42	42
	0.0	0.0	0.0	0.3	0.0	0.0	12.2	17.5	29.0	33.1	0.0	35.0	28.5	49.1	58.3
	0.1	0.0	0.0	0.3	0.0	0.0	12.6	18.1	29.5	33.6	0.0	35.8	29.3	47.8	57.8
	0.0	0.0	0.0	0.0	0.0	0.1	12.4	17.4	29.2	34.1	0.1	34.4	29.3	46.6	58.1
vg.	0.0	0.0	0.0	0.2	0.0	0.0	12.4	17.7	29.2	33.6	0.0	35.1	29.0	47.8	58.1
vg.	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.43	0.73	0.82	0.00	1.37	1.13	1.88	2.28
vg.	0.00	0.00	0.00	0.00	0.01	0.00	0.27	0.54	1.02	1.24	0.00	2.45	2.00	3.07	3.33
						28	28	28	28	28	14	14	14	14	14
						109	109	109	109	109	56	56	56	56	56
						0.0	10.7	15.4	24.3	26.0	0.0	26.2	21.8	36.9	45.8
						0.0	10.9	15.7	25.2	29.3	0.0	27.1	20.9	35.5	45.8
						0.0	10.7	15.5	24.2	29.1	0.0	26.1	21.8	35.[illegible]	45.9
vg.						0.0	10.8	15.5	24.6	28.8	0.0	26.5	21.2	36.0	45.8
vg.						0.00	0.23	0.34	0.55	0.63	0.00	1.03	0.82	1.42	1.81
vg.						0.00	0.26	0.49	0.90	1.09	0.00	2.09	1.71	2.66	2.95
											14	14	14	14	14
											70	70	70	70	70
A											0.4	20.5	16.5	27.0	37.8
B											0.0	20.4	16.6	27.2	37.5
C											0.0	20.1	17.0	25.5	38.0
Avg.											0.1	20.3	16.8	26.6	37.8
Avg.											0.00	0.79	0.65	1.05	1.49
Avg.											0.00	1.0[illegible]	1.49	2.33	2.66

rates are known to be high because of the presence of Teflon.

ion MPY Increment.
ion MPY Accumulative.

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TABLE 13

CORROSION RATES OF 5086-H34 ALUMINUM IN STATIC N_2O_4 IN TEFLON-LINED A

PENETRATION IN MILS PER YEAR

Temperature		-9°C(15°F)					46°C(115°F)				
Water Added, Wt %		0.0	0.2	0.4	0.8	1.6	0.0	0.5	1.0	2.0	3.0
Days in Period		14	14	14	14	14	28	28	28	28	28
mg Loss	A	0.2	0.2	0.9	20.4	27.9	0.4	29.2	116.4	334.3	518.6
	B	0.2	0.4	0.7	23.0	33.4	0.4	30.3	63.1	333.8	515.3
	C	0.6	0.4	0.7	21.4	29.6	0.4	31.0	108.4	359.4	545.2
	Avg.	0.3	0.3	0.8	21.6	30.3	0.4	30.2	96.0	342.5	526.4
Penetration(1)	Avg.	0.05	0.04	0.10	2.88	4.04	0.03	1.98	6.28	22.31	34.61
Penetration(2)	Avg.	0.05	0.04	0.10	2.88	4.04	0.03	1.98	6.28	22.31	34.61
Days in Period		21	21	21	21	21		28	28	28	28
Days Total		35	35	35	35	35		56	56	56	56
mg Loss	A	0.0	0.0	1.4	6.9	15.5		17.7	21.6	15.4	14.1
	B	0.0	0.0	0.9	7.7	15.5		18.4	20.7	15.5	14.4
	C	0.0	0.0	0.9	6.5	22.5		18.0	22.6	14.9	14.1
	Avg.	0.0	0.0	1.1	7.0	17.8		18.0	21.6	15.3	14.2
Penetration(1)	Avg.	0.00	0.00	0.09	0.63	1.59		1.18	1.41	0.99	0.94
Penetration(2)	Avg.	0.03	0.02	0.10	1.76	2.82		1.58	3.85	11.65	17.78
Days in Period		21	21	21	21	21		25	25	25	25
Days Total		56	56	56	56	56		81	81	81	81
mg Loss	A	0.0	0.3	0.8	4.8	9.9		10.8	14.3	8.3	7.8
	B	0.0	0.5	0.8	7.0	10.1		12.1	15.4	7.2	7.6
	C	0.0	0.6	1.0	5.5	8.8		11.4	14.3	6.2	6.4
	Avg.	0.0	0.5	0.9	5.8	9.6		11.4	14.7	7.2	7.3
Penetration(1)	Avg.	0.00	0.04	0.08	0.51	0.85		0.84	1.08	0.52	0.53
Penetration(2)	Avg.	0.02	0.03	0.09	1.34	2.16		1.33	2.92	7.94	12.03
Days in Period							81	28	28	28	28
Days Total							109	109	109	109	109
mg Loss	A						0.0	9.1	11.2	6.2	6.7
	B						0.0	9.3	10.9	5.8	7.4
	C						0.0	9.5	10.8	5.6	7.2
	Avg.						0.0	9.3	11.0	5.9	7.1
Penetration(1)	Avg.						0.00	0.61	0.72	0.39	0.47
Penetration(2)	Avg.						0.02	1.15	2.37	6.05	9.14
Days in Period											
Days Total											
mg Loss	A										
	B										
	C										
	Avg.										
Penetration(1)	Avg.										
Penetration(2)	Avg.										

(1) Penetration MPY Increment.
(2) Penetration MPY Accumulative.

TABLE 13

-H34 ALUMINUM IN STATIC N_2O_4 IN TEFLON-LINED ALUMINUM CONTAINERS

PENETRATION IN MILS PER YEAR

(15°F)		46°C(115°F)					74°C(165°F)				
0.8	1.6	0.0	0.5	1.0	2.0	3.0	0.0	0.5	1.0	2.0	3.0
14	14	28	28	28	28	28	14	14	14	14	14
20.4	27.9	0.4	29.2	116.4	334.3	518.6	0.3	69.5	219.1	337.7	757.3
23.0	33.4	0.4	30.3	63.1	333.8	515.3	0.3	77.1	231.0	324.8	456.4
21.4	29.6	0.4	31.0	108.4	359.4	545.2	0.4	65.7	211.2	365.8	453.0
21.6	30.3	0.4	30.2	96.0	342.5	526.4	0.3	70.8	220.4	342.8	555.6
2.88	4.04	0.03	1.98	6.28	22.31	34.61	0.04	8.50	26.79	41.45	67.54
2.88	4.04	0.03	1.98	6.26	22.31	34.61	0.04	8.50	26.79	41.45	67.54
21	21		28	28	28	28	14	14	14	14	14
35	35		56	56	56	56	28	28	28	28	28
6.9	15.5		17.7	21.6	15.4	14.1	0.0	3.6	0.0	1.9	4.4
7.7	15.5		18.4	20.7	15.5	14.4	0.0	3.4	0.0	2.1	5.0
6.5	22.5		18.0	22.6	14.9	14.1	0.0	4.3	0.0	1.7	5.7
7 0	17.8		18.0	21.6	15.3	14.2	0.0	3.8	0.0	1.9	5.0
0.63	1.59		1.18	1.41	0.99	0.94	0.00	0.45	0.00	0.23	0.61
1.76	2.82		1.58	3.85	11.65	17.78	0.02	4.48	13.40	20.84	34.08
21	21		25	25	25	25	14	14	14	14	14
56	56		81	81	81	81	42	42	42	42	42
4.8	9.9		10.8	14.3	8.3	7.8	0.2	6.4	0.8	5.0	8.7
7.0	10.1		12.1	15.4	7.2	7.6	0.0	5.7	0.9	4.5	7.5
5.5	8 8		11.4	14.3	6.2	6.4	0.0	5.9	0.7	4.6	6.6
5.8	9.6		11.4	14.7	7.2	7.3	0.1	6.0	0.8	4.7	7.6
0.51	0.85		0.84	1.08	0.52	0.53	0.00	0.72	0.10	0.57	0.92
1.34	2.16		1.33	2.92	7.94	12.03	0.01	3.22	8.96	14.08	23.02
		81	28	28	28	28	14	14	14	14	14
		109	109	109	109	109	56	56	56	56	56
		0.0	9.1	11.2	6.2	6.7	0.4	12.0	1.7	0.7	1.3
		0.0	9.3	10.9	5.8	7.4	0.1	11.4	2.6	1.0	1.3
		0.0	9.5	10.8	5.6	7.2	0.0	11.2	0.9	0.7	1.4
		0.0	9.3	11.0	5.9	7.1	0.2	11.5	1.7	0.8	1.3
		0.00	0.61	0.72	0.39	0.47	0.02	1.39	0.31	0.10	0.16
		0.02	1.15	2.37	6.05	9.14	0.02	2.77	6.80	10.59	17.31
							14	14	14	14	14
							70	70	70	70	70
							0.1	1.3	2.0	1.1	8.5
							0.3	1.5	2.1	1.0	8.0
							0.2	1.1	0.9	1.1	7.3
							0.2	1.3	1.7	1.1	7.9
							0.03	0.16	0.20	0.13	0.96
							0.02	2.24	5.48	8.50	14.04

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EFFEC

		SERIES A								S
Container Dia. x Length		3-3/16" x 11-11/16"								4-1/
Material		Stainless Steel 304								Stai
Vol. N_2O_4, ml		300	300	300	300	300	300	600	600	600
H_2O, Wt %		1	1	1	1	1	1	3	3	3
Metal Exposed		Carbon Steel (1)						Carbon Steel(1)		Alun
Metal Area, sq. cm		24.8	24.8	24.8	24.8	24.8	24.8	32.4	33.7	31.4
Teflon Present		Yes	No	Yes	No	Yes	No	Yes	No	Yes
Kind Teflon		Gar-lock		Air Force		Gar-lock		Air Force		Air For
Area Teflon, sq. cm		322		322		322		322		322
g H_2O/sq. cm metal		0.017	0.017	0.017	0.017	0.017	0.017	0.79	0.76	0.8
sq. cm Teflon/g N_2O_4		0.75	-	0.75	-	0.75	-	0.38	-	0.3
Temp., °C		Room temperature, ca. 25°C						74	74	74
Days Exposure		17	17	19	19	14	14	6	6	6
Losses, mg	1	11.6	3.9	1.5	1.9	15.1	12.4	1184	113	396
	2	12.0	3.0	1.4	1.9	17.5	12.4	1175	111	402
	3									
	Avg.	11.8	3.5	1.5	1.9	16.3	12.4	1179	112	399
Penetration, MPY	Avg.	1.1	0.3	0.1	0.15	1.7	1.3	22[illegible]	20.1	240

(1) Carbon Steel ASTM A285 Grade C

TABLE 14

EFFECT OF TEFLON

			SERIES B							SERIES C					
"			4-1/4" x 11-1/2"							4-1/4" x 11-1/2"					
4			Stainless Steel 304L							Stainless Steel 304L					
	300	300	600	600	600	600	600	600	600	600	600	600	600	600	600
	1	1	3	3	3	3	3	3	3	1	1	2	2	3	3
			Carbon Steel(1)		Aluminum 5086		Stainless Steel 304L			Carbon Steel (1)					
	24.8	24.8	32.4	33.7	31.4	31.6	35.9	35.9	30.9	34	34	34	34	34	34
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No
	Gar-lock 322		Air Force 322		Air Force 322		Air Force 322		Gar-lock 322	Air Force 322		Air Force 322		Air Force 322	
	0.017	0.017	0.79	0.76	0.82	0.81	0.72	0.72	0.83	0.25	0.25	0.50	0.50	0.75	0.75
	0.75	-	0.38	-	0.38	-	0.38	-	0.38	0.38	-	0.38	-	0.38	-
a. 25°C			74	74	74	74	74	74	74	46	46	46	46	46	46
	14	14	6	6	6	6	10	10	7	7	7	7	7	7	7
	15.1	12.4	1184	113	396	241	11	0.4	5	31.9	2.7	307	4.9	259.8	2.8
	17.5	12.4	1175	111	402	410	11	0.4	5	34.8	1.2	273	4.9	250.5	11.5
	16.3	12.4	1179	112	399	326	11	0.4	5	32.4	2.0	285	4.9	255.2	7.3
	1.7	1.3	221	20.1	240	186	1.08	0.04	0.87	5.1	0.3	44.4	0.75	39.0	1.1

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TABLE 15

CORROSION RATES OF CARBON STEEL (ASTM A285 GRADE C) IN

PENETRATION IN MILS PER YE

Temperature		-9°C (15°F)						21°C (70°F)						
Water Added, Wt %		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0
Days in Period		3	3	3	3	3	3	3	3	3	3	3	3	3
mg Loss	A	0.8	0.6	0.7	0.3	0.5	1.3	0.4	0.5	0.2	0.9	5.7	6.3	0.8
	B	0.9	0.6	0.7	0.7	0.8	0.5	0.3	0.3	0.0	0.7	5.9	7.0	0.9
	C	0.9	0.9	0.3	0.8	0.6	1.3	0.4	0.2	0.2	1.0	5.4	7.6	0.8
	Avg.	0.9	0.7	0.6	0.6	0.6	1.0	0.4	0.3	0.1	0.9	5.7	7.0	0.8
Penetration, mpy	Avg.	0.52	0.42	0.32	0.33	0.39	0.57	0.22	0.18	0.08	0.49	3.40	3.91	0.47
Days in Period		9	9	9	9	9	9	9	9	9	9	9	9	9
mg Loss	A	0.3	0.3	0.3	1.0	1.2	1.1	0.7	0.2	0.1	2.1	14.9	19.2	0.2
	B	0.4	0.3	0.6	1.2	1.2	0.9	0.0	0.4	0.3	1.9	16.0	20.7	0.2
	C	0.2	0.5	0.4	1.3	1.0	1.0	1.5	0.4	0.4	2.2	14.3	20.5	0.2
	Avg.	0.3	0.4	0.4	1.2	1.1	1.0	0.7	0.3	0.3	2.1	15.1	20.1	0.2
Penetration, mpy	Avg.	0.06	0.07	0.08	0.21	0.23	0.19	0.14	0.06	0.05	0.39	3.00	3.77	0.04
Days in Period		27	27	27	27	27	27	27	27	27	27	27	27	27
mg Loss	A	0.1	0.6	0.7	2.0	2.1	2.0	0.0	1.4	0.3	5.2	49.6	60.9	0.2
	B	0.2	0.2	0.6	1.6	2.1	1.9	0.1	1.4	0.4	5.7	47.8	73.2	0.3
	C	0.1	0.6	0.4	1.8	1.4	1.8	0.1	0.7	0.5	5.6	44.4	73.9	0.3
	Avg.	0.1	0.5	0.6	1.8	1.9	1.9	0.1	1.2	0.4	5.5	47.3	69.3	0.3
Penetration, mpy	Avg.	0.01	0.03	0.04	0.11	0.12	0.12	0.01	0.08	0.03	0.34	3.15	4.32	0.02

TABLE 15

OF CARBON STEEL (ASTM A285 GRADE C) IN STATIC N_2O_4 IN CAPPED GLASS TUBES

PENETRATION IN MILS PER YEAR

21°C (70°F)						49°C (120°F)						74°C (165°F)					
.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
.4	0.5	0.2	0.9	5.7	6.3	0.8	0.6	0.5	0.8	21.4	48.7	0.7	0.5	0.9	31.5	119.4	345.3
.3	0.3	0.0	0.7	5.9	7.0	0.9	0.5	1.1	0.8	21.5	54.8	1.2	0.4	1.0	10.8	116.3	342.7
.4	0.2	0.2	1.0	5.4	7.6	0.8	0.4	0.4	0.9	22.8	55.2	0.9	0.8	1.0	36.6	73.1	206.3
.4	0.3	0.1	0.9	5.7	7.0	0.8	0.5	0.7	0.8	21.9	52.9	0.9	0.6	1.0	26.3	102.9	298.1
.22	0.18	0.08	0.49	3.40	3.91	0.47	0.29	0.40	0.55	12.54	32.77	0.58	0.32	0.57	15.68	63.71	166.42
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
.7	0.2	0.1	2.1	14.9	19.2	0.2	0.3	4.9	32.3	109.6	244.8	0.3	0.3	1.3	42.8	222.5	534.8
.0	0.4	0.3	1.9	16.0	20.7	0.2	0.2	4.5	33.8	130.3	293.2	0.3	0.4	1.4	46.3	265.5	534.4
.5	0.4	0.4	2.2	14.3	20.5	0.2	0.1	3.8	22.9	62.9	115.9	0.3	0.3	1.0	25.7	149.6	363.6
.7	0.3	0.3	2.1	15.1	20.1	0.2	0.2	4.4	29.7	100.9	218.0	0.3	0.3	1.2	38.3	212.5	477.6
.14	0.06	0.05	0.39	3.00	3.77	0.04	0.04	0.92	6.47	19.35	44.88	0.06	0.06	0.24	7.69	42.49	89.33
7	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
.0	1.4	0.3	5.2	49.6	60.9	0.2	2.8	16.3	75.7	293.7	436.8	0.6	3.5	18.9	57.6	218.3	441.2
.1	1.4	0.4	5.7	47.8	73.2	0.3	3.4	15.5	85.0	332.1	506.3	0.5	2.8	21.8	60.9	234.1	448.7
.1	0.7	0.5	5.6	44.4	73.9	0.3	1.0	10.9	58.0	146.5	354.0	0.2	2.9	11.5	27.5	126.0	309.8
.1	1.2	0.4	5.5	47.3	69.3	0.3	2.4	14.2	72.9	257.4	432.4	0.4	3.1	17.4	48.7	192.8	399.9
.01	0.08	0.03	0.34	3.15	4.32	0.02	0.16	0.99	5.29	16.49	29.72	0.03	0.19	1.12	3.25	13.58	27.50

TABL...

CORROSION RATES OF TYPE 304-L STAINLESS ST...

PENETRATION IN M...

Temperature		-9°C (15°F)						21°C (70°F)					
Water Added, Wt %		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.
Days in Period		-	-	-	-	-	3	3	3	3	3	3	3
mg Loss	A	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.
	B	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.
	C	-	-	-	-	-	0.0	0.0	0.0	0.0	0.1	0.0	0.
	Avg.	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.
Penetration, mpy	Avg.	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.
Days in Period		9	9	9	9	9	9	9	9	9	9	9	9
mg Loss	A	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.1	0.2	0.3	0.
	B	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.3	0.2	0.
	C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.2	0.
	Avg.	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.3	0.2	0.
Penetration, mpy	Avg.	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.03	0.06	0.05	0.
Days in Period		27	27	27	27	27	27	27	27	27	27	27	27
mg Loss	A	0.1	0.2	0.3	0.2	0.2	0.2	0.0	0.3	0.3	0.4	0.5	0.
	B	0.2	0.3	0.1	0.2	0.2	0.2	0.1	0.3	0.2	0.1	0.4	0.
	C	0.0	0.3	0.2	0.3	0.1	0.3	0.1	0.3	0.3	0.2	0.4	0.
	Avg.	0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.3	0.2	0.4	0.
Penetration, mpy	Avg.	0.01	0.02	0.01	0.02	0.01	0.02	0.00	0.02	0.02	0.02	0.03	0.
Days in Period													
mg Loss	A												
	B												
	C												
	D												
	E												
	Avg.												
Penetration, mpy	Avg.												

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TABLE 16

RATES OF TYPE 304-L STAINLESS STEEL IN STATIC N_2O_4 IN CAPPED GLASS TUBES

PENETRATION IN MILS PER YEAR

21°C (70°F)						49°C (120°F)						74°C (165°F)					
0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.12
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
0.5	0.2	0.1	0.2	0.3	0.4	0.3	0.1	0.0	0.0	0.2	0.3	0.5	0.2	0.3	0.0	0.4	0.2
0.2	0.1	0.0	0.3	0.2	0.2	0.2	0.1	0.3	0.3	0.3	0.4	0.5	0.2	0.4	0.0	0.2	0.2
0.0	0.2	0.3	0.3	0.2	0.5	0.2	0.2	0.0	0.2	0.3	0.1	0.3	0.2	0.3	0.0	0.2	0.2
0.2	0.2	0.1	0.3	0.2	0.4	0.2	0.1	0.1	0.2	0.3	0.3	0.4	0.2	0.2	0.0	0.3	0.2
0.05	0.03	0.03	0.06	0.05	0.08	0.06	0.03	0.02	0.04	0.06	0.06	0.10	0.04	0.05	0.00	0.06	0.05
27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
0.0	0.3	0.3	0.4	0.5	0.3	0.2	0.2	0.4	0.2	0.4	0.6	2.6	0.0	0.1	0.2	0.1	0.2
0.1	0.3	0.2	0.1	0.4	0.4	0.4	0.2	0.1	0.2	0.3	0.5	2.1	0.0	0.2	0.0	0.0	0.2
0.1	0.3	0.3	0.2	0.4	0.4	0.0	0.0	0.3	0.1	0.2	0.3	2.1	0.2	0.2	0.2	0.0	0.3
0.1	0.3	0.3	0.2	0.4	0.4	0.2	0.1	0.3	0.2	0.3	0.5	2.3	0.1	0.2	0.1	0.0	0.2
0.00	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.02	0.02	0.02	0.04	0.19	0.00	0.02	0.01	0.00	0.02
												27	27	-	-	-	-
												0.2	0.0	-	-	-	-
												0.2	0.0	-	-	-	-
												0.3	0.2	-	-	-	-
												0.4	0.0		-	-	-
												0.1	0.2	-	-	-	-
												0.2	0.1	-	-	-	-
												0.02	0.00	-	-	-	-

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TABLE 17

CORROSION RATES OF 5086-H34 ALUMINUM IN STAT

PENETRATION IN MILS

Temperature		-9°C (15°F)						21°C (70°F)					
Water Added, Wt %		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
Days in Period		3	3	3	3	3	3	3	3	3	3	3	3
mg Loss	A	0.0	0.0	0.1	0.8	0.9	1.2	0.0	0.0	0.2	0.7	9.7	27.0
	B	0.0	0.0	0.1	0.8	1.1	1.1	0.0	0.0	0.1	0.8	9.4	30.0
	C	0.0	0.0	0.2	0.8	1.1	1.4	0.0	0.0	0.2	0.7	9.0	31.3
	Avg.	0.0	0.0	0.1	0.8	1.0	1.2	0.0	0.0	0.2	0.7	9.4	29.4
Penetration, mpy	Avg.	0.00	0.00	0.27	1.59	2.06	2.42	0.00	0.00	0.34	1.46	18.93	59.80
Days in Period		9	9	9	9	9	9	9	9	9	9	9	9
mg Loss	A	0.0	0.0	0.0	3.4	4.4	6.6	0.0	0.0	0.0	1.1	13.4	22.3
	B	0.0	0.0	0.0	3.4	5.0	7.0	0.0	0.0	0.1	1.0	12.9	23.5
	C	0.0	0.0	0.0	3.1	4.4	7.3	0.0	0.0	0.0	1.3	12.2	23.0
	Avg.	0.0	0.0	0.0	3.3	4.[illegible]	7.0	0.0	0.0	0.0	1.1	12.8	22.9
Penetration, mpy	Avg.	0.00	0.00	0.00	2.23	3.06	4.55	0.00	0.00	0.00	0.75	8.64	15.53
Days in Period		27	27	27	27	27	27	27	27	27	27	27	27
mg Loss	A	0.0	0.0	0.2	10.2	14.3	16.5	0.0	0.2	0.7	3.5	14.8	28.7
	B	0.0	0.1	0.3	12.5	15.1	16.3	0.0	0.0	0.7	3.6	13.4	29.5
	C	0.0	0.0	0.4	11.6	12.1	17.0	0.0	0.0	0.6	3.6	12.9	37.3
	Avg.	0.0	0.0	0.3	11.4	13.8	16.6	0.0	0.1	0.7	3.6	13.7	31.8
Penetration, mpy	Avg.	0.00	0.00	0.07	2.57	3.07	3.61	0.00	0.01	0.15	0.79	3.07	7.20

TABLE 17

N RATES OF 5086-H34 ALUMINUM IN STATIC N_2O_4 IN CAPPED GLASS TUBES

PENETRATION IN MILS PER YEAR

	21°C (70°F)						49°C (120°F)						74°C (165°F)					
.0	0.2	0.4	0.8	1.6	3.2		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
	3	3	3	3	3		3	3	3	3	3	3	3	3	3	3	3	3
0	0.0	0.2	0.7	9.7	27.0		0.3	0.3	1.2	2.5	19.8	39.2	0.3	0.3	2.6	15.4	38.7	75.6
0	0.0	0.1	0.8	9.4	30.0		0.3	0.3	1.3	2.4	21.5	39.5	0.4	0.4	2.7	16.0	49.0	75.5
0	0.0	0.2	0.7	9.0	31.3		0.1	0.3	1.3	2.4	16.2	37.4	0.3	0.2	1.9	15.5	46.0	73.1
0	0.0	0.2	0.7	9.4	29.4		0.2	0.3	1.3	2.4	19.2	38.7	0.3	0.3	2.4	15.6	44.6	76.1
00	0.00	0.34	1.46	18.93	59.80		0.45	0.58	2.47	4.74	37.34	75.39	0.67	0.60	4.74	30.61	88.33	152.51
	9	9	9	9	9		9	9	9	9	9	9	9	9	9	9	9	9
0	0.0	0.0	1.1	13.4	22.3		0.2	0.6	1.6	15.9	60.9	124.8	0.1	0.1	3.8	23.8	56.7	85.1
0	0.0	0.1	1.0	12.9	23.5		0.0	0.5	1.9	14.6	62.9	129.9	0.0	0.1	3.2	24.3	65.8	154.9
0	0.0	0.0	1.3	12.2	23.0		0.0	0.6	1.7	8.1	44.7	78.0	0.0	0.1	2.8	22.1	49.4	117.4
0	0.0	0.0	1.1	12.8	22.9		0.1	0.6	1.7	12.9	56.9	110.9	0.0	0.1	3.3	23.4	57.3	119.1
00	0.00	0.00	0.75	8.64	15.53		0.04	0.36	1.12	8.35	36.39	72.01	0.00	0.06	2.15	15.28	37.95	79.35
	27	27	27	27	27		27	27	27	27	27	27	27	27	27	27	27	27
0	0.2	0.7	3.5	14.8	28.7		0.0	0.8	1.8	19.2	44.0	295.7	0.2	0.2	8.3	37.6	80.6	223.4
0	0.0	0.7	3.6	13.4	29.5		0.0	0.8	1.5	19.4	44.0	319.0	0.2	0.2	7.7	38.5	89.0	214.5
0	0.0	0.6	3.6	12.9	37.3		0.0	0.5	1.6	6.6	44.8	187.1	0.2	0.0	7.1	36.5	75.0	216.8
0	0.1	0.7	3.6	13.7	31.8		0.0	0.7	1.6	15.1	44.3	267.3	0.2	0.1	7.7	37.5	61.5	218.2
00	0.01	0.15	0.79	3.07	7.20		0.00	0.15	0.35	3.26	9.59	57.85	0.04	0.02	1.69	8.17	17.59	48.60

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TABLE

CORROSION RATES OF PH 15-7 Mo STAINLESS STE

PENETRATION IN M

Temperature		-9°C (15°F)						21°C (70°F)					
Water Added, Wt. %		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
Days in Period		3	3	3	3	3	3	3	3	3	3	3	3
mg Loss	A	0.1	0.0	0.3	0.0	0.2	0.1	0.1	0.3	0.2	0.2	0.4	0.5
	B	0.2	0.2	0.0	0.3	0.3	0.0	0.0	0.0	0.4	0.3	0.4	0.6
	C	-	0.1	0.0	0.2	0.1	0.2	0.0	0.1	0.3	0.3	0.6	0.6
	Avg.	0.2	0.1	0.1	0.2	0.2	0.1	0.0	0.1	0.3	0.3	0.5	0.6
Penetration, mpy	Avg.	0.11	0.07	0.07	0.13	0.15	0.08	0.00	0.10	0.22	0.20	0.35	0.43
Days in Period		9	9	9	9	9	9	9	9	9	9	9	9
mg Loss	A	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.1	0.1	0.1	0.3	0.0
	B	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.4	0.3
	C	-	0.0	0.1	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.2	0.4
	Avg.	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.3	0.2
Penetration, mpy	Avg.	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	0.02	0.02	0.07	0.06
Days in Period		27	27	27	27	27	27	27	27	27	27	27	27
mg Loss	A	+0.3	0.2	0.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.3
	B	+0.2	0.1	0.1	0.5	0.3	0.0	+0.2	0.0	0.0	0.0	0.3	0.3
	C	-	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.6	0.6
	Avg.	0.0	0.1	0.1	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.4
Penetration, mpy	Avg.	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.03

+ indicates Gain

TABLE 18

RATES OF PH 15-7 Mo STAINLESS STEEL IN STATIC N_2O_4 IN CAPPED GLASS TUBES

PENETRATION IN MILS PER YEAR

21°C (70°F)						45°C (120°F)						74°C (165°F)					
.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
.1	0.3	0.2	0.2	0.4	0.5	0.0	0.2	0.2	0.1	0.3	0.5	0.1	0.0	0.1	0.1	2.8	2.4
.0	0.0	0.4	0.3	0.4	0.6	0.0	0.0	0.0	0.3	0.3	0.7	0.3	0.0	0.0	1.0	2.1	2.6
.0	0.1	0.3	0.3	0.6	0.6	0.0	0.0	0.0	0.0	0.3	0.8	0.1	0.0	0.3	0.4	2.2	3.8
.0	0.1	0.3	0.3	0.5	0.6	0.0	0.1	0.1	0.1	0.3	0.7	0.2	0.0	0.1	0.5	2.4	2.9
.00	0.10	0.22	0.20	0.35	0.43	0.00	0.05	0.05	0.10	0.22	0.51	0.13	0.00	0.09	0.37	1.81	2.10
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
.0	0.1	0.1	0.1	0.3	0.0	0.2	0.2	0.6	0.5	1.4	1.5	0.1	0.4	0.4	0.5	1.0	3.9
.0	0.0	0.2	0.2	0.4	0.3	0.2	0.1	0.4	0.5	1.2	1.9	0.4	0.1	0.3	0.9	1.5	3.2
.0	0.0	0.0	0.0	0.2	0.4	0.1	0.1	0.4	0.3	0.6	1.4	0.2	0.3	0.4	1.0	1.6	3.0
.0	0.0	0.1	0.1	0.3	0.2	0.2	0.1	0.5	0.4	1.1	1.6	0.2	0.3	0.4	0.8	1.4	3.2
.00	0.00	0.02	0.02	0.07	0.06	0.04	0.03	0.12	0.11	0.26	0.41	0.06	0.07	0.09	0.20	0.35	0.81
7	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
0	0.0	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.5	0.9	1.6	+0.2	0.0	0.0	0.3	0.5	5.5
2	0.0	0.0	0.0	0.3	0.3	0.0	+0.2	0.0	0.9	0.8	1.8	+0.3	0.0	0.0	1.0	0.8	4.4
0	0.0	0.0	0.0	0.6	0.6	0.0	0.1	+0.1	1.0	0.3	1.6	0.0	0.0	0.0	0.7	0.7	4.6
0	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.8	0.7	1.7	0.0	0.0	0.0	0.7	0.7	4.8
.00	0.00	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.07	0.06	0.14	0.00	0.00	0.00	0.06	0.06	0.39

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TABLE 19

CORROSION RATES OF 75-A AND 6Al-4V TITANIUM IN STATIC N_2O

PENETRATION IN MILS PER

Titanium		75-A						75-A						
Temperature		21°C (70°F)						74°C (165°F)						
Water Added, Wt. %		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0
Days in Period		-	-	-	-	-	-	9	9	9	9	9	9	-
mg Loss	A	-	-	-	-	-	-	+0.3	+0.3	0.0	+0.2	+0.1	+0.1	-
	B	-	-	-	-	-	-	+0.4	+0.3	0.0	0.0	+0.2	+0.2	-
	C	-	-	-	-	-	-	+0.5	+0.4	0.0	+0.1	0.0	+0.2	-
	Avg.	-	-	-	-	-	-	+0.4	+0.3	0.0	+0.1	+0.1	+0.2	-
Penetration, mpy	Avg.	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-
Days in Period		27	27	27	27	27	27	27	27	27	27	27	27	27
mg Loss	A	0.0	0.3	0.2	0.0	0.0	0.1	0.2	0.0	0.0	0.4	0.3	0.3	0.2
	B	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.4	0.2	+0.2
	C	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.3	0.0	0.0
	Avg.	0.0	0.2	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.2	0.3	0.2	0.0
Penetration, mpy	Avg.	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00

\+ Indicates Gain

TABLE 19

75-A AND 6Al-4V TITANIUM IN STATIC N_2O_4 IN 304-L STAINLESS STEEL CONTAINERS

PENETRATION IN MILS PER YEAR

75-A					6Al-4V						6Al-4V					
74°C (165°F)					21°C (70°F)						74°C (165°F)					
0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
9	9	9	9	9	-	-	-	-	-	-	9	9	9	9	9	9
+0.3	0.0	+0.2	+0.1	+0.1	-	-	-	-	-	-	+0.5	+0.2	+0.2	0.0	+0.2	+0.1
+0.3	0.0	0.0	+0.2	+0.2	-	-	-	-	-	-	+0.4	+0.2	0.0	+0.2	+0.2	+0.2
+0.4	0.0	+0.1	0.0	+0.2	-	-	-	-	-	-	+0.4	+0.2	+0.2	+0.2	+0.2	+0.3
+0.3	0.0	+0.1	+0.1	+0.2	-	-	-	-	-	-	+0.4	+0.2	+0.1	+0.1	+0.2	+0.2
0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
0.0	0.0	0.4	0.3	0.3	0.2	+0.1	+0.1	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.2	0.0
0.0	0.0	0.2	0.4	0.2	+0.2	+0.2	0.1	0.0	0.0	0.1	0.0	0.0	+0.3	0.0	0.4	0.2
0.0	0.2	0.0	0.3	0.0	0.0	+0.3	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.1	0.2	0.3	0.2	0.0	+0.2	0.0	0.0	0.0	0.2	0.0	0.0	+0.1	0.0	0.2	0.1
0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00

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TABLE 20

SUMMARY OF CORROSION RATES OF METALS TESTED IN STATIC
STEEL CONTAINERS

PENETRATION IN MILS PE

Temperature	-9°C (15°F)						21°C (70°F)					
Water Added, Wt %	0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
Days in Period												CARBON STEEL AS
3	0.52	0.42	0.32	0.33	0.39	0.57	3.22	0.15	0.08	0.49	3.40	3.91
9	0.06	0.07	0.00	0.21	0.23	0.19	0.14	0.06	0.05	0.39	2.00	3.77
27	0.01	0.03	0.04	0.11	0.12	0.12	0.01	0.03	0.03	0.34	3.15	4.32
												TYPE 304-L STA
3	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.03	0.06	0.05	0.08
27	0.01	0.02	0.01	0.02	0.01	0.02	0.00	0.02	0.02	0.02	0.03	0.03
27	-	-	-	-	-	-	-	-	-	-	-	-
												5086-H34 A
3	0.00	0.00	0.27	1.59	2.06	2.42	0.00	0.00	0.34	1.46	18.93	59.80
9	0.00	0.06	0.00	2.23	3.06	4.55	0.00	0.00	0.00	0.75	8.64	15.53
27	0.00	0.00	0.07	2.57	3.07	3.61	0.00	0.01	0.15	0.79	3.07	7.20
												PH 15-7 Mo STAINLESS STEEL
3	0.11	0.07	0.07	0.13	0.15	0.08	0.00	0.10	0.22	0.20	0.35	0.43
9	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	0.02	0.02	0.07	0.06
27	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.09	0.04	0.03
												75-A TI
9	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	0.00	0.01	0.01	0.00	0.00	0.00
												6Al-4V T
9	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.01
												WELDED 5086
27	0.02	-	[illegible].38	-	-	[illegible].65	0.01	-	0.38	-	-	5.65

TABLE 20

ION RATES OF METALS TESTED IN STATIC N_2O_4 IN CAPPED GLASS TUBES AND 304-L STAINLESS STEEL CONTAINERS

PENETRATION IN MILS PER YEAR

21°C (70°F)						49°C (120°F)						74°C (165°F)					
0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
CARBON STEEL ASTM A-285 GRADE C																	
0.22	0.18	0.08	0.49	3.40	3.91	0.47	0.29	0.40	0.55	12.54	32.77	0.58	0.32	0.57	15.68	63.71	166.42
0.14	0.06	0.05	0.39	3.00	3.77	0.04	0.04	0.92	6.47	19.35	44.88	0.06	0.06	0.24	7.69	42.49	89.33
0.01	0.08	0.03	0.34	3.15	4.32	0.02	0.16	0.99	5.29	16.49	29.72	0.03	0.19	1.12	3.25	13.50	27.50
TYPE 304-L STAINLESS STEEL																	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
0.05	0.03	0.03	0.06	0.05	0.08	0.05	0.03	0.02	0.04	0.06	0.06	0.10	0.04	0.05	0.00	0.06	0.05
0.00	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.02	0.02	0.02	0.04	0.17	0.00	0.02	0.01	0.00	0.02
-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.00	-	-	-	-
5086-H34 ALUMINUM																	
0.00	0.00	0.34	1.46	18.93	59.80	0.45	0.58	2.47	4.74	37.34	75.39	0.67	0.60	4.74	30.61	88.33	152.51
0.00	0.00	0.00	0.75	8.64	15.53	0.04	0.36	1.12	3.35	36.39	72.01	0.00	0.06	2.15	15.28	37.95	79.45
0.00	0.01	0.15	0.79	3.07	7.20	0.00	0.15	0.35	3.26	9.59	57.85	0.04	0.02	1.69	8.17	17.99	48.60
PH 15-7 Mo STAINLESS STEEL (ARMCO CONDITION RH 950)																	
0.00	0.10	0.22	0.20	0.35	0.43	0.00	0.05	0.05	0.10	0.22	0.51	0.13	0.00	0.09	0.37	1.81	2.10
0.09	0.00	0.02	0.02	0.07	0.06	0.04	0.03	0.12	0.11	0.26	0.41	0.66	0.07	0.09	0.20	0.35	0.81
0.00	0.00	0.00	0.00	0.04	0.03	0.60	0.00	0.00	0.07	0.06	0.14	0.00	0.00	0.00	0.06	0.06	0.3[illegible]
75-A TITANIUM																	
-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.01	0.01	0.00	0.00	0.00	-	-	-	-	-	-	0.00	0.00	0.00	0.01	0.01	0.01
6Al-4V TITANIUM																	
-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.01	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.01	0.00
WELDED 5086 ALUMINUM																	
0.01	-	0.38	-	-	6.65	0.02	-	1.53	-	-	23.95	0.02	-	5.11	-	-	32.35

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TABLE 21

CORROSION RATES OF WELDED 5086 ALUMINUM IN STATIC N_2O_4 IN CAPPED GLASS TUBES

Days in Period	Temp. °C	Wt. % Water Added to N_2O_4	Specimen No.	Mg. Loss	Corrosion Rate, MPY	Condition of Sample Around Weld
				PENETRATION IN MILS PER YEAR		
27	-9	0.0	A	0.5	0.02	No attack.
		0.4	B	43.8	1.38	Slight attack on weld interface.
		3.2	C	52.5	1.65	Slight attack on weld interface.
27	21	0.0	A	0.3	0.01	No attack.
		0.4	B	12.1	0.38	Slight attack. Weld hardly visible.
		3.2	C	217.3	6.65	Heavy general corrosion. Weld easily visible.
27	49	0.0	A	0.5	0.02	No attack.
		0.4	B	48.8	1.53	Slight attack. Weld hardly visible.
		3.2	C	443.5	23.95	Heavy general corrosion. Weld easily visible.
27	74	0.0	A	0.6	0.02	No attack.
		0.4	B	166.4	5.11	Slight corrosion. Weld visible.
		3.2	C	1057.5	32.35	Heavy general corrosion. Weld easily visible.

One face of each welded specimen was filed smooth around weld area. Observations were made on this face of specimen.

TABLE 22

COMPATIBILITY OF COMMERCIAL N_2O_4 AND ELASTOMERS AT 25°C

Elastomer	Days In Test	Observations
Tygon	66	Tubing shrunk to one-half its original size, turned dark green in color, and on standing in atmosphere it became hard and would crack when bent.
Hypalon Rubber	20	Disintegrated.
Nylaflow Hose	7	Disintegrated.
Viton "B" Rubber	9	Swelled twice its original size, very soft and much more flexible than original sample.
Koroseal	9	Tubing showed some shrinkage, turned green in color, and became hard on standing. This tube burst at 1000 psig. (Untested tubing swelled at 100 psig and burst at 400 psig).
Hycar 5-T Rubber	12	Disintegrated.
Thiokol 3600 ST-C Rubber	-	Disintegrated immediately on contact with N_2O_4.
Acid Seal MA Rubber	-	Disintegrated immediately on contact with N_2O_4.
Silastic Rubbers		
No. 59711-2-480	7	Crumbled.
No. LS-53-24-300	7	Swelled twice its original size.
No. 50-24-400	7	Crumbled.
No. 651	3	Crumbled.
Hysunite Acid Discharge Hose (Goodyear)	3	Inside liner of hose swelled, blistered, very soft, and much more flexible than original sample.

TABLE 23

CORROSION RATES OF METALS AND NON-METALL

Run No.	
Hours of Test	
Recirculating N_2O_4	
Gallons Per Minute	
Temperature Range	26
Pressure on Reservoir	7 psig
Discharge Pressure	50 psi

Location of Specimen in Assembly	Material		Observation and Corr	
Specimen Container	PH 15-7 Mo Stainless Steel	1	Rates Based on	0.00
		2	101 hours continuous	0.00
		3	circulating time	0.00
	304-L Stainless Steel	4		0.04
		5		0.04
		6		0.02
	5086 Aluminum	1		0.00
		6		0.00
		4		0.00
	Carbon Steel - ASTM A-285	7		0.39
	Grade C	8		0.26
		9		0.31
		10		0.24
		11		0.23
Impingement Holder	Carbon Steel - ASTM A-285 Grade C	1		0.23
	304-L Stainless Steel	2		-
Non-Metallic Tubes	Kel-F		Stretched 1/2" in length, swe turned tan in color. Remove dynamic test.	
	Teflon			-
Reservoir Specimens	Koroseal		Shrunk slightly and became h	
	Alathon		Crumbled.	
	Polyvinyl Chloride		Swelled and became soft and	
	Kel-F		No change in size, but slightl	
	Lucoflex Polyvinyl Chloride		Swelled and became soft and	
	Teflon		Discolored and became softer	
	Johns-Manville Service Asbestos		Blistered and showed some sl	
	African Blue Asbestos		Good condition.	
	Teflon Impregnated Asbestos-Palmetto 1330		Good condition.	

Elbows in Assembly
- 3 - Type 304 Stainless Steel
- 2 - Carbon Steel

Welded Nipples in Assembly
- 1 - Carbon Steel
- 1 - Type 304 Stainless Steel
- 1 - Aluminum (grade not known)

TABLE 23

ON RATES OF METALS AND NON-METALLIC MATERIALS IN FLOWING N_2O_4

		1 101 12.5 26 - 31°C 7 psig - maximum 50 psig - average				2 104 12.5 25 - 32°C 8 psig - maximum 50 psig - average		
	Observation and Corrosion Rates in MPY				Observation and Corrosion Rates in MPY			
1	Rates Based on	0.00	Rates Based on	0.00	Rates Based on	0.00	Rates Based on	0.00
2	101 hours continuous	0.00	total time speci-	0.00	104 hours con-	0.00	total time speci-	0.00
3	circulating time	0.00	mens were in	0.00	tinuous circulat-	0.00	mens were in	0.00
4		0.04	assembly, 20 days	0.01	ing time	0.04	assembly, 6 days	0.03
5		0.04		0.01		0.00		0.00
6		0.02		0.00		0.00		0.00
1		0.00		0.00		0.17		0.12
6		0.00		0.00		0.11		0.08
4		0.00		0.00		0.05		0.03
7		0.39		0.08		0.72		0.51
8		0.26		0.05		0.16		0.1[illegible]
9		0.31		0.07		0.17		0.13
10		0.24		0.05		0.62		0.46
11		0.23		0.05		0.16		0.11
1		0.23		0.05		-		-
2		-		-		0.00		0.00

Test 1:

Stretched 1/2" in length, swelled .025" in diameter, turned tan in color. Removed after 2-1/2 hours of dynamic test.

-

	Shrunk slightly and became hard on standing.
	Crumbled.
	Swelled and became soft and flexible.
	No change in size, but slightly discolored.
	Swelled and became soft and flexible.
	Discolored and became softer.
...os	Blistered and showed some shrinkage.
	Good condition.
...almetto 1330	Good condition.

Test 2:

-

Stretched 3/8" in length, swelled 0.01" in diameter, turned tan in color. Removed after 205 hours of dynamic tests.

All elbows remained in original condition and showed no weight loss during 205 hours of dynamic test.

Cross-section specimens from each of the welded nipples were examined and found in good condition after 205 hours of dynamic tests.